# Optimisation of rebreeding strategy in UK Holstein dairy cattle- a multifactorial study

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Thesis submitted to Plymouth University
in fulfilment of the requirements for the degree of
ResM Agriculture and Food, 2015

**Plymouth University**

**Faculty of Science & Technology**

in collaboration with
**National Milk Records plc, UK**

with assistance from

**European Regional Development Fund Convergence 2007-13**

ACKNOWLEDGEMENTS:

I would like to thank my supervisors, Dr Jes Scaife, Dr Tim Whittaker and Dr Hayley Randle for their invaluable advice and support throughout this project and both Duchy College and the School of Biomedical and Biological Sciences for their assistance.

I would also like to thank National Milk Records plc for both their support for my undertaking this study but also the assistance and supply of data necessary to facilitate the project. I also acknowledge the contribution made by the ERDF in development of the study program across Cornwall Colleges and all assistance given.

Finally I would like to thank my family for their patience and assistance throughout the duration of the project.

## AUTHOR'S DECLARATION

At no time during the registration for the ResM degree has the author been registered for any other University award without prior agreement of the Graduate Sub-Committee.

Work submitted for this research degree at Plymouth University has not formed part of any other degree either at Plymouth University or at another establishment.

This study was financed with the aid of a studentship from National Milk Records plc. A programme of advanced study was undertaken which included taught modules and associated internal university development courses. Relevant scientific seminars and conferences were regularly attended at which work was presented.

**Publications**

BSAS Conference proceedings April 2013 Vol4 Part 1 Page 50

BSAS Conference proceedings April 2014 Vol 5 Part 1 Page 99

**Presentation and Conferences Attended**

CARS conference December 2013; poster presentation

BSAS Conference, Putting science into practice, April 2013; presentation

BSAS Conference, Technologies to tackle global food challenges, April 2014; presentation

CARS conference June 2014; presentation

**Word count of main body of thesis: 24092**

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**Abstract**

Dairy production in the UK has undergone a period of sustained increase both in number of cows held in each unit and yields per cow. Whilst much of this yield increase can be attributed to nutritional science, the production capacity of individual animals has also contributed significantly through both higher peak yields and greater persistency of production throughout lactation. This additional production has not come without cost which has manifested itself as a general decrease in reproductive performance. Although the associated lengthening of the calving interval has led to an increase in herd average days in milk, the question arises whether the flatter lactation curves observed in modern animals make the traditional targets of calving at 365 day intervals less relevant. It could be conjectured that, taking into account all of the major cost factors, extension of lactation in modern animals may be economically advantageous.

This work created a bio economic model in investigation of the above question using bespoke production modelling based upon current UK production information combined with costs and other income levels relevant to the analysis period. The results were presented as income per cow per day of intercalving interval indicating daily contribution to the herd economics regardless of reproductive performance.

The results indicated that the effects of poorer reproductive performance and longer voluntary waiting periods are variable and inversely proportional to increasing yields. For the highest yielding herds early resumption of breeding and conception brings considerable advantage which is driven by the differential between peak and late lactation yields. Increasing average days in milk has a detrimental effect upon production that is greater than the dilution of fixed costs over more days in the calving interval. For the lowest yielding herds the converse was shown with corresponding increases in income per day with increasing lactation length although of very low order. For all production levels analysed replacement rate was the single most important factor affecting income and, as such, indicates why fertility should be the major focus of Holstein breeding. Improved fertility would reduce both calving intervals and involuntary cull levels having a two fold positive effect upon herd economics.

The voluntary waiting period was the least significant of the economic factors investigated, the results indicating variable effects by both length of voluntary waiting period and yield level. The economic significance of voluntary waiting period length increases relatively with yield however earlier rebreeding was financially advantageous across almost all yield levels. Although the financial impact of voluntary waiting period length is of low order it is the single factor which is completely in control of the herd management policy. Not withstanding welfare effects, these results would suggest that rebreeding at the earliest opportunity in high yielding animals remains the optimal breeding policy.

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## Abbreviations

**VWP** Voluntary waiting period

**BCS** Body condition score

**RR** Replacement rate

**PR** Pregnancy rate

**CI** Calving interval

**ici** Inter calving interval

# 1. Background

## 1.1 Feeding a Growing World

### 1.1.1 World population and production predictions

Feeding the growing world population is one of the challenges facing humanity in the medium term. The FAO (2002) estimates that world demand for food will increase annually by 1.4% for the period 2015 – 2030 compounding to a 23% increase in demand over those 15 years. World population growth is predicted to be 0.9% per annum through that period so the FAO predicts that sufficient feed supplies will be available. However at the time of the report it was estimated that 17% of the population in developing countries were undernourished and, with population growth estimated to run at 1.1% per annum in these countries, their estimated growth in food requirement to meet current and future requirements will be 1.7% per annum.

Increasing efficiency in production and availability of low cost food from existing resource will have growing importance in assisting with climate change policy and delivery. Cheap, easily available food will mitigate the need to convert more land to food production and lower commodity prices will enhance the relative value of compensation schemes in the most sensitive areas.

### 1.1.2 The shift from cereal based to meat and dairy based diets

Dietary change is associated with improving economies in the developing countries leading directly to change in food requirements (Schmidhuber & Shetty, 2005). Currently the developed countries show the highest levels of calorific intake per day (FAO, 2002), however as developing economies become more affluent they also move towards a more calorific "western" diet. This effect is known as the nutrition transition and defines a shift from primary food sources (cereals) first towards processed cereal products then moving increasingly towards dairy and meat based diets as incomes increase and the price of food relative to income becomes lower. This leads not only to increasing calorific intake but also reduces overall food efficiency due to the involvement of animals in the food chain (Schmidhuber & Shetty, 2005). Dairy and dairy based products are both aspirational and play an important role in improving nutrition in these developing economies

### 1.1.3 The global dairy industry

Dairy production is one of the key global agricultural sectors due both to the nutritional value of the raw product but also to the increasing range of additional products that can be produced from whole milk and milk based derivatives. FAO statistics show that, in 2012, 620 million tonnes of cows milk were produced globally, a rise of thirteen million tonnes on the previous year with anecdotal estimates suggesting an equivalent value of c$500b. The predicted increases in world population combined with the outlined shift in dietary patterns across the rapidly developing economies suggests that the industry should see continued growth in demand in the short to medium term.

In terms of volume, the UK is currently the worlds 10th highest producer of cows milk producing 13.2 million tonnes annually. However, this represents a decline of 1.4 million tonnes (-9.5%) since 1998 at which point the UK was the world's 7th largest producer with an output of 14.6 million tonnes (Hawkins, 2011). Following a long period of stagnant low milk prices and imposition of the quota system, in 2008 the UK milk production volume was at its lowest level since 1974 (Dairyco, 2009). The EU quota system was introduced in 1984 and the fundamental objective was to reduce milk production to counter food surpluses. These high levels of oversupply had been encouraged and supported by previous decisions at EC level to increase availability and thereby reduce the cost of product to the consumer. Clearly the previous support policies had proved successful with households spending about 10% of income on food in 2011 as opposed to 30% in the previous generation (Boulton *et al,* 2012), however the introduction of quotas in 1984 had a dramatic effect on the dairy industry across Europe. EU figures estimate that just one in seven of those producing milk in 1984 are currently active indicating that about 85% of producers have quit the industry in the intervening 30 years, trends in the UK are certainly similar with just 43% of active producers from 1995 remaining in 2015 (Dairy co, 2012).

## 1.2 Review of the Industry and project background

### 1.2.1 Recording and genetic improvement

The industry has a long history of continuous improvement in production, efficiency and development of scale. As with any program of improvement, performance monitoring has been a key component in driving these changes especially over the last 100 years.

Since the implementation of dairy performance recording systems in the early 20th century, the production performance data required to selectively breed for enhanced performance in dairy cattle has become more readily available and increasingly utilised both on a national and global scale. These recording systems were initially introduced by individual breed societies and clubs which expanded into national bodies and have ultimately developed, under the auspices of The International Committee for Animal Recording (ICAR), into a network of organisations uniformly applying the internationally agreed rules for recording and evaluation across all breeds and countries. These standards have facilitated global comparisons particularly in the testing and proof of breed improving sires. These high genetic merit sires combined with use of artificial insemination have given the opportunity for leading international animal genetics to be used at local level (Berglund,2008) thus giving a rapid change to the quality of genetics in many herds. Complimenting this, the data collected has also been used at individual farm level to assist in the selection of breeding females and these two specific uses of the recorded data have combined to give a continual improvement in cow performance. Of particular note and international importance are the changes observed within the Holstein breed where a combination of selective animal breeding combined with improved nutritional and management techniques have seen an increase in UK average individual animal yields from 4747kg in 1958 to 8785 kg in 2008

(CDI, 2012). As referenced by Boulton et al (2012), It is estimated that improved genetics have contributed 50% to this overall improvement (Boyns, 2009)

### 1.2.2 Nutrition and herd management

Whilst genetic selection has led to enhanced performance potential, nutritional science and improved feeding systems have enabled this production potential to be exploited. At the upper end of herd production, many units keep animals housed permanently. This gives the ability to both feed consistent rations regardless of weather or time of year but also to tailor the rations to meet the nutritional requirements of cows across a range of production stages within the lactation. It is also the case that permanently housed systems remove the need for sufficient grazing within a suitable distance hence these units are not limited in terms of numbers held upon one site, the UK average herd size increased by 50% in the 15 years prior to 2012 (Dairyco, 2012) and over 30% of US dairy cows were held in herds of 500+ animals by 2001 (Lucy, 2001).

High input herds are managed on an all year round calving system which means that poor reproductive performance can be masked by apparently high levels of milk sales. Infertility is often associated with higher yielding herds. Many managers accept it as an unwanted outcome of production pressure on cows however the intangible costs of sub optimal fertility can be high (Stott et al, 1999; Inchaisri et al, 2010; Esslemont and Peeler, 1993). These high input high output units focus upon production of good quality home grown forage combined with high levels of purchased concentrates or straights to give the required nutrient density hence feed costs per litre produced tend to be the greatest both per cow and per kg produced.

A large proportion of UK herds do graze at some level, although this has considerable cost savings grass shows much variation in quality depending upon variety, stage of growth and prevailing weather conditions. This makes grazing unsuitable for very high yielding herds due to the inconsistency combined with the lack of nutrient density. For herds where aspirational yields are lower, the cost savings given by an effective grazing regime mean that they can be as profitable as high yielding systems, these units are often described as medium input medium output. Infertility remains a problem within these herds resulting from inconsistent rations and the prevalence of the Holstein breed.

The UK features a growing number of low input systems based upon spring calving and grazing principles. The focus of this management system is for cows to calve annually within a tight block system hence fertility is vital to ensure adequate production the following year. Predominantly the focus for herd selection and external purchased genetics is to breed increasingly fertile animals, as a result infertility is not a common problem within this system but it is also suggested that the use of alternative breeds and cross breeding avoids the deterioration in reproductive performance associated with Holsteins. A tendency towards some cross breeding has been observed in medium input herds recently in a bid to improve fertility and health through heterogeneity however the main of the UK dairy herd remains Holstein based.

### 1.2.3 Holstein genetics and infertility

There is much evidence that modern Holstein genetics have introduced weaknesses into the breed, particularly in reducing levels of fertility (Walsh et al, 2011; Berglund, 2008). A 2009 study of US Holsteins (Norman et al 2009) highlighted these issues as illustrated by their published data on mean reproductive performance between 1996 and 2007. Most notable were the reduction in calving to first service interval (92 days reduced to 85), increase in number of services required (2.1 to 2.5) and also a resultant increase in calving index from 410 days to 422. Hence, although breeding was being commenced earlier overall there was a decline in CI. Similar trends have been observed by other authors (Inchaisri et al, 2010). Trends in the UK have been similar, in 2009 CR were reducing by 1% per year (Huxley, 2009) with calving indexes having increased from 396 days in 1998 to 426 days in 2009 (Boulton, 2012).

This combination of increasing yields with decreasing fertility has been described in many papers due to the negative economic impact of sub optimal fertility (Friggens et al, 2010; Albarrán-Portillo and Pollott, 2013; Dobson et al, 2007). More widely recognised as the production reproduction antagonism, there is a very large body of research both on the physiology and economics of the condition in respect of animal welfare and financial implications.  On discussion of reducing the economic  impacts of the antagonism there are counter arguments for extending lactation (Friggens et al, 2010, Dobson et al, 2007) or commencing breeding earlier ( Inchaisri et al, 2011) highlighting the complex nature of the welfare, physical and economic attributes of the problem.

As fertility has declined in the breed there has been a concurrent trend towards commencing breeding much earlier in the lactation than in the past (Boulton et al, 2012; Berglund, 2012). Traditionally cows were bred with the intention of calving annually hence breeding was commenced around day 60 post partum thus giving an average CI of around 365 days. Over the last 20 years the length of time elapsing between calving and service (the VWP) has been reducing to 40 days or lower in some instances, the reasons for this are two fold. Due to the lower reproductive performance of the animals this strategy gives more opportunities to serve cows without increasing CI but some studies have also suggested that the earlier in lactation a cow conceives, the greater her production value to the herd (Inchaisri et al, 2011; Meadows et al, 2005; Esslemont and Peeler, 1993; Stott et al, 1999; Groenendaal et al, 2004). This is due to the fact that more cows are in peak lactation at any given time in the herd (Berglund, 2012) however this simplistic approach to maximising production does not necessarily take account of counter productive financial implications in what amounts to a complex multi factorial problem. The financial effects of the reduction in VWP across the dairy industry per se but particularly in the Holstein breed have been researched and enumerated many times, often with conflicting outcomes (Arbel et al, 2001, Dobson et al, 2007; Meadows et al, 2005; Inchaisri et al, 2011; Stott et al, 1999). This project aims to investigate the causes, results and economic implications of these practices in the UK against the backdrop of the production climate and circumstances outlined previously.

## 1.3 Fertility, production and management practice, a review

### 1.3.1 Increasing lactation length, choice or consequence?

Reduced fertility in the national herd has a deleterious effect on economic performance which anecdotal evidence suggests costs over £500million annually. Many papers have enumerated the economics of fertility problems in dairy cattle (Arbel et al, 2001; Inchaisri et al, 2011; Groenendaal et al, 2004; Stott et al, 1999) with wide ranging results. Higher cull rates and reduced milk sales are the main factors whilst direct increased costs (service, veterinary intervention) account for the remainder. The reduced milk sales result from increasing lactation length (Pryce et al, 2004; Albarrán-Portillo and Pollott, 2013) however, in purely economic terms, counter arguments exist that extension of lactation may be beneficial (Dobson et al, 2007; Pryce et al, 2004). High persistency levels in the Holstein breed stimulate this debate with pre dry yields suggesting wasted opportunities to extend profitable lactation length (Inchaisri et al, 2010). Although within herd peer comparison's may suggest that extending lactation in higher yielding animals enhance profitability, providing that suitable quality and number of replacements are available early rebreeding of these animals should be optimal (Lee et al, 1997).

Discussion of optimal lactation length creates challenges for industry advisors in respect of best practice with both short and long lactations suggested as preferable. In favour of extending lactation, financial advantage has been based upon exploiting persistency based upon lower later lactation yields being balanced by reduced early lactation feed costs, lower veterinary intervention costs, reduced cull rates and dilution of replacement cost over increased lifetime (Dobson et al, 2007). Avoiding early gestation effect upon yield (Olori et al, 1997) whilst exploiting modern persistency and reduced exposure to high risk periods (Dobson et al, 2007) have given further arguments in favour of extending lactation. A final but negative justification is that modern genetics and farming practice make previous fertility targets impractical (Friggens et al, 2010). Conversely Inchaisri et al (2011) indicated that for 90% of cows a VWP of less than 9 weeks was optimal, within this 37% were best suited to a vwp of less than 6 weeks, similarly Meadows et al (2005) suggested that reducing both herd turnover and days open were financially advantageous whilst Groenendaal et al (2004) indicated that early breeding enhances profits.

This highlights the problem facing farm decision makers on choosing between extended lactation or minimal days open. The complex multifactorial economic relationships would indicate that each herd but possibly every individual animal would have an optimal rebreeding stage (Meadows et al, 2005; Inchaisri et al, 2011) dependent upon individual factors of maximum yield, persistency, lactation number and fertility index alongside the herd level factors of RR and availability of replacements. While economics offer no definitive solution, practical problems exist within both scenarios that add further complexity.

Against extended lactations, reducing risk periods (Dobson et al, 2007) are countered by reduced recovery opportunities from yield impact events. It may be considered that reducing risk periods equates to extending working life through increased lactation length, total risk events per lifetime remain the same but frequency of events is reduced, thus lactations per lifetime remain constant but productive lifetime is increased. Although evidence exists of lower mean production per day of ici with increasing lactation length (Arbel et al, 2001; Van Arendonk et al, 1989) it has also been shown that conception in early lactation has greater impact upon production (Olori et al, 1997) hence earlier conception may reduce production more significantly over an increased proportion of the lactation. Some animals would not achieve the suggested economic levels of persistency (Dobson et al, 2007), similarly as animals mature persistency weakens (Arbel et al, 2001) further undermining economic argument. Evidence would suggest that insufficient late production may lead to subsequent parturition with increased body condition and associated risks of ketosis, displaced abomasums and milk fever linked to negative energy balance (Rukkwamsuk et al, 1999), depressed feed intake may impact upon production in the subsequent lactation. It is generally accepted that primiparous animals offer higher levels of persistency (Inchaisri et al, 2011; Arbel et al, 2001) and other work has shown that the impact of early conception upon yield is greater for these animals (Olori et al, 1997), this would suggest that extended lactations in first lactation animals may offer more significant economic advantage.

The work cited indicates that production persistency is the determining viability factor for extending lactations however it is also recognised that higher levels of persistency are associated with lower yield in early lactation and later peak yield (Cole, 2009; Albarrán-Portillo and Pollott, 2013; Dobson et al, 2007). Lower, later peak yields would impact upon milk sales per day, combined with uncertainties of persistency levels in individual animals this would mean that any cost savings in respect of inputs and reduced culls would need to at least equate to the level of lost income for the system to be viable. It is also suggested that if the average days open in the herd exceeds 160 then there may be insufficient female animals reared to sustain the herd (Meadows et al, 2005; Boulton et al, 2012).

A conclusion from this may be that the individual optimal rebreeding dates may offer a solution (Inchaisri et al, 2011; Arbel et al, 2001). With genomic testing offering qualitative data on production level, lifetime and persistency traits it could be conjectured that, applied through suitable optimisation programs, the possibility to tailor optimal rebreeding dates may become a useful strategy.

Much of the research analysis of performance in extended lactations is based upon secondary data. This form of data may be distorted by not knowing the reason why extended lactations occur (Arbel et al, 2001). They infer that this may lead to performance analysis of a sample group with above average incidence of problems delaying conception as opposed to lactation extension by predetermined management. This would suggest that, for some members of the sample group, early lactation and peak yields may be compromised impacting upon assessment of extending lactation. This raises a wider question on unintended and intended extended lactations, it may be considered that a proportion of animals in secondary data sets with extended lactations are exhibiting direct results of infertility and other problems as opposed to selective later breeding.

In the wider discussion, a management strategy to optimise extended lactations across a herd would offer efficiencies in breeding, feed and intervention costs that would not be reflected in a herd where extension is the outcome of poor fertility. Use of sires offering high persistency combined with careful selection of the female breeding base may mean that systems outlined by Dobson et al (2007) could be economically successful.

### 1.3.2 Current breeding policy and reproductive performance

A national survey of 500 herds found that 51% of cows were served before day 80 post partum (Hanks and Kossaibati, 2012) with a VWP of 40-60 days (Ferguson and Skidmore, 2009) indicating that shorter lactations are considered economically preferable. As illustrated in 1.2.1, production per cow increased by 35% between 1995 and 2010 (Defra, 2011), so this raises the question of what effects the early resumption of service and conception has on high yielding cows.

First the definition of high yielding should be considered, this may be a measure of average herd performance or *relatively* high yielding would encompass animals within a herd with above average production (Dobson et al, 2007). Ouweltjes et al (1996) indicated that relatively high yielding cows were served later, that would be due to either a management decision or some physiological effect delaying oestrus. From this it may be concluded that actual yield level does not lead to changes in breeding performance; by the definition of *relative* an animal producing 10000kg per year could be considered a low or a high yielder depending upon peer performance and, from the Ouweltjes et al (1996) observation, the time elapsing between calving and service would be linked to her production level *relative* to the herd mean. The observation that farmers delay service on high yielding animals (Inchaisri et al, 2010;  Lee et al, 1997) has some effect however a proportion will be due to yield affecting reproductive performance. This would concur with research on the physiology of infertility highlighting that some cows partition resource successfully towards reproduction and production whilst others favour production to the detriment of reproductive performance (Lucy, 2001; Friggens et al, 2010). Within similarly managed animals those that extract more milk will be displaying either enhanced efficiency or allocating more resource to production which may explain why some relatively high yielding cows show poorer reproductive performance. A full review of the physiology of infertility in the Holstein breed is outside of the scope of this work but section 1.3.5. covers the important aspects in more detail.

An economically important relationship is that between RR and reproductive performance. The 2012 review of 500 herds (Hanks and Kossaibati, 2012) indicated a cull rate of 26% while Dairyco (2009) estimated  that 24% of all culls were involuntary for fertility reasons. It is unlikely that these figures would vary much in their respective publishing years suggesting that ~6% of the national herd is lost annually through infertility. Reproductive performance and cull rate have a direct relationship that is controlled by individual business managers. Some herds continue serving viable cows through long periods whilst others set a maximum breeding threshold. The two scenarios offer considerably different reproductive performance statistics but the question of economic return is complex with  similar arguments to those given in respect of extended lactations including;

Comparison of the two scenarios suggests that extending breeding threshold would reduce RR but increase CI resulting in lower production through increased average days in milk. The former is key as RR is the second largest direct cost to producers (FBS, 2013) and it has been shown that higher ratios of multiparous animals enhance overall production (Groenendaal et al, 2004).

Alternatively a maximum breeding threshold increases milk output by reducing average days in milk (Ferguson and Skidmore, 2009) and reduces service costs per cow, anecdotal evidence suggests that this strategy may improve fertility as replacements are bred from animals exhibiting good fertility. Herds with high RR have higher ratios of heifers to cows, the effects of this are threefold; Firstly heifer yields are lower and so setting a breeding threshold may not optimise milk output. Secondly, heifers are more likely to suffer negative energy balance and associated problems (Lucy, 2001) so increasing heifer ratios may further increase cull rates. Thirdly increased RR may enhance the herd through introduction of improved genetics (Groenendaal et al, 2004) but Van Arendonk et al (1985) indicated that genetic improvement did not offer viable reasons to increase RR. It has been shown that extension of  CI is less financially damaging in high yielding herds (Groenendaal et al, 2004)indicating that optimal RR will vary by herd.

In conclusion it is apparent that shorter lactations are considered preferable under current UK management practice but manipulation of CI by increasing RR may be economically  antagonistic.

Evidence suggests that short CI are optimal where they occur due to good reproductive management and herd fertility as opposed to a cull and replace management policy.

### 1.3.3 Current performance

Accepting the paradigm that shorter lactations are preferable, this raises the question of how effectively these are currently achieved. The 2012 study (Hanks and Kossaibati) indicated that median PR was 19.5% and that 28% of cows were pregnant by day 100. Assuming that similar fertility performance is achieved between days 100 and 200 pp it might be estimated that a lower bound for open cows at day 200 would be circa 25% suggesting that at least a quarter of UK Holstein cows may have a CI in excess of 500 days.

### 1.3.4 Effects of poorer reproductive performance on individual animals

With a significant proportion of the UK Holstein herd recording long CI it raises the question of how this impacts upon performance at individual animal level. One important factor is the effect of gestation upon yield, previous work has shown that the effect of conception upon production is negative and increasing as conception occurs earlier in lactation (Olori et al, 1997; Ouweltjes et al, 1996; Lee et al, 1997). In terms of production recording this effect would translate into enhanced levels of recorded 305 day lactation for animals conceiving later in lactation, Lee (1997) enumerated this within his study group and indicated that, for multiparous animals, the mean difference in 305 day lactation total for animals conceiving at day 290 as opposed to day 40 was an increase of 1613 kg (Lee et al, 1997). The author found a similar trend in the UK data set (Miller et al, 2014), with higher yielding cows recording 1121kg higher 305 day lactation totals when conceiving at day 160 as opposed to day 40.

An outcome of the higher 305 day lactation totals recorded by later conceiving animals would be that analysis of reproductive performance based upon that parameter would show a correlation between higher production and poor reproductive performance. The yield effects of early conception mean that this is a mixture of cause and result as opposed to being indicative of the cause (Miller et al, 2014) suggesting that the 305 day production total is biased towards animals exhibiting extended days open. This has wide implications as 305 day lactation totals are used widely within research but also in breeding decisions at farm level. At herd level, selection using performance based upon 305 day production would be naturally biased towards less fertile animals as they demonstrate the higher levels of production. There is potential for a similar effect on the male selection lines as sire dams are generally selected from elite production groups which could be biased towards later conceiving animals. Much current research across many aspects of dairy production use the 305 day yield as a standard comparator but this would suggest it does not truly represent individual animal performance. The effect of conception upon yield has been widely established (Olori et al, 1997; Ouweltjes et al, 1996; Lee, 1997) however there is an additional problem with the use of 305 day lactation that Lee (1997) had observed but did not elucidate which is caused by the use of short VWP. We can observe that conception before day 75 post partum, allowing for a gestation period of 285 days and a 56 day dry period, would result in these animals not completing 305 days and, for each day prior to day 75 pp that they conceive, the number of days contributing to the 305 day total would decrease by one (Miller et al, 2014). In first lactation animals it was observed that mean 305 day lactation total increased by 876kg as conception days post partum increased from 30 to 100 but for conception between days 100 and 200 there was a much smaller increase of 172kg (Lee et al, 1997). This creates challenges in respect of production comparators for the most fertile animals, these results suggest that the current international yield metric is biased against those animals which are considered most desirable under current management practice.

. Although the 305 day yield is the main comparator for individual animal production globally, organisations such as Interbull and Dairyco mitigate the effects of varying lactation length on production analytics through the use of BLUP (Best Linear Unbiased Prediction) methodology to create estimated breeding values (EBVs). This approach establishes unbiased predictors for traits through establishing a predictor that mimimses variance given a data set and suitable error factors (https://prezi.com/gncpacbh6ecy/best-linear-unbiased-estimators/). For milk production evaluations these principles are applied using all test day weighing data as opposed to a lactation total (whether natural or 305 day) hence all weighing data is incorporated, the use of BLUP then allows the separation of true genetic effects from environmental factors allowing for accurate breeding values.

The first amalgamated UK breeding index(£PIN, Dairyco) was based purely upon production, it was considered that these may have been detrimental to UK herd fertility due to the ongoing reduction in reproductive performance. This situation was analysed by Wicks and Lever (2004) in their review into the effect of genetic merit indices on cattle reproductive performance. They found no significant correlation between genetic merit for milk production and calving to conception interval however two other findings were of note. Daily milk production level at day 90 had no significant influence on number of services per conception but they also observed that there was an increase in services required per conception with increasing 305 day yield. Considering these two observations and those previously shown on the effect of conception upon yield (Olori et al, 1997; Loeffler et al, 1999), this suggests that the observation of increasing services does not indicate a direct relationship with yield but rather those animals that require more services and so conceive later produce enhanced 305 day totals. A final observation from their study concluded that selection based upon genetic merit for production would bias selection towards animals displaying increased levels of anoestrus and an ovulation (Wicks and Lever (2004).

The suggestion of a potential weakness in the production metric has been eluded to previously. Van Arendonk et al indicated in 1989 that there were negative correlations between yield and days open citing earlier work by Phillipson (1981) who indicated that, due to the effect of increasing days open on 305 day lactation totals, genetic comparison should be made with comparators of production made in early lactation. It was concluded that "*selection for production will result in an unfavourable correlated response in fertility*" (Van Arendonk et al, 1989). Against the backdrop of these known shortfalls, the introduction of indices based purely upon production and the decline in fertility throughout the period of use would appear to be circumstances that to some degree could have been mitigated. This idea is given further credence by 2 counter examples, primarily in the UK population where, since the introduction of a second generation amalgamated index based upon type, lifetime and production traits (£pli), it has been observed that the decline in fertility performance has been arrested (Hanks and Kossaibati, 2012). Secondly, in the Scandinavian Red breeds there has been no deterioration in reproductive performance with increasing yield (Berglund,2008) but the indices were based upon multiple traits of which production formed part, it was also noted that the rate of increase in average yield had been lower than in the Holstein breed. In Sweden, Holstein animals managed and bred using the same index system did show a reduction in reproductive efficiency however it was suggested that this was a result of imported genetics. Although overall fertility has been retained in the Scandinavian reds infertility is still recorded as the most important cause of involuntary culls in Sweden (Berglund,2008).

In summary, reduced fertility is a proven weakness of the modern Holstein breed strongly linked to genetic selection based upon production traits. Heritability of fertility traits are of low order (c5%) however additive genetic variation is high (Berglund,2008) which would imply that over multiple generations the compounding effects could give a significant change in the breed characteristic.

### 1.3.5 Lower fertility in Holstein cattle, an overview

It is widely established that the Holstein breed has undergone a sustained period of reducing fertility which appears to have reached nadir. The physiology of the problem is outside of the scope of this project however there are some aspects of the problem which require inclusion and discussion. The genetic selection for yield giving cows that hold lower body condition combined with a prolonged period of negative energy balance in early lactation and the effects of these conditions on complex endocrine functions are commonly cited as the reasons for this decline (Roche et al, 2000; Friggens et al, 2010). Lucy completed a review of the literature in 2001 which suggested that yield and production were not necessarily the direct cause of deteriorating fertility but that the observed decline resulted from combinations of multiple causes, he cited Nebel and Mcgilliard (1993) on their observation that higher yielding herds have better fertility. The cited work was published before the current circumstances but many cows do still achieve optimal fertility (Ouweltjes et al, 1996) and the author’s current experience with a group of elite herds would suggest that high yielding herds with matching standards of management are achieving CI under 400 days without excessive RR. These herds and the previous observation provide a counter example to the generalisation of the reproduction production antagonism across the wider population and introduce a discussion on the circumstances behind poorer reproductive performance.

It has been observed that yield level may not be directly causative but that a higher predominance of other problems which negatively affect fertility are found in higher yielding animals (Lucy, 2001). This could indicate why production level is associated with infertility even though evidence from a comparative analysis of peer reviewed reports indicated that fertility *in general* had declined over a 7 year period (Lucy, 2001). It has already been shown that some herd managers delay service on higher yielding animals (Inchaisri et al, 2010; Lee et al, 1997) leading to negative correlations between conception timing and increasing yield however it has been shown that higher lactation total is correlated with an increase in services per conception (Loeffler et al, 1999; Wicks and Lever, 2004). This would be independent of decisions on service timing and may suggest that yield has some effect upon fertility. Higher yields are associated with increased prevalence of disorders which lengthen the interval between calving and conception (Lucy, 2001; Dobson et al, 2007; Ingvartsen et al, 2003; Fourichon et al, 1999). It was proposed that declining fertility is common to all production levels in Holsteins but that the prevalence of such disorders with increasing yield gives rise to the yield to infertility correlation (Lucy, 2001). Dobson et al, (2007) cited work from Borsberry and Dobson (1989) and Collick et al (1989) showing resultant delays of 42 days (lameness), 26 days (endometritis), 16 days (milk fever), 8 days (retained foetal membranes) and 7 days (Mastitis). Later work also indicated that increased somatic cell count affected fertility and conception where service occurred within 28 days of the incidence (Hudson et al, 2012). This would indicate that individual animals can show significant effects from any disorder in early lactation however Loeffler et al (1999) suggested that the accumulated effect of weaker fertility across the wider herd was probably of greater significance than the sum of individual cases. This would suggest that herd fertility in general has weakened while the increased prevalence of disorders in higher production animals has substantiated the yield based observation.

In the discussion of declining fertility, inbreeding has become increasingly prevalent within the breed (Walsh et al, 2011; Berglund,2008; Lucy, 2001). Lucy (2001) cited work by Hansen (2000) indicating that inbreeding levels in the US Holstein population was 5% in 2000 and projected to be 10% by 2020. He also indicated from previous published work that for each 1% increase in inbreeding corresponding increases of 0.17 services per conception, 2 days increased days open and a 3.3% decline in CR could be observed (Hemas et al, 1987). Cows with higher levels of inbreeding also suffer higher levels of dystocia and stillbirth (Walsh et al, 2011), in the context of prevalence of disorders affecting fertility these would be linked to increased retained foetal membranes and endometritis.

It has also been observed that various features of modern high input dairy units have potential impact upon fertility levels. These units, where cows are housed all year on total mixed ration systems, are associated with high yields further substantiating the high yield poor fertility discussion. Lucy (2001) cited earlier work by Britt et al (1986) indicating that standing surface had a direct impact on oestrus expression and mount times with cows on a dirt floor exhibiting 15 times more standing oestrus than those on concrete. Flooring surface and duration of standing heat were cited as two reasons why less than half of heat events were observed (Ferguson and Skidmore, 2009).

As indicated in section 1.3, herds which suffer poor fertility will either accept reduced milk sales (Meadows et al, 2005) or decide to apply higher cull rates due to the increased involuntary culls for fertility reasons. The latter gives a higher proportion of first calf heifers in the herd which, due to the constraints of production, continuing growth to maturity, competition with senior animals and lower feed intake capacity, will be more susceptible to the causes of infertility. As indicated by Lucy (2001), this can lead to further decline in production, fertility and age structure within the herd.

The above highlights some causes of infertility and why they are more prevalent in high yielding animals but, for completeness, negative energy balance (NEB) needs inclusion in the review. This area is dominated by high level physiological description outside of the scope of this review however it is important to note that the increased prevalence of disorders affecting fertility are correlated to NEB (Walsh et al, 2011; Roche et al, 2000; Loeffler et al, 1999), while Ingvartsen et al (2003) indicated that the rate of body reserve mobilisation is closely mapped to that of disease incidence . It was observed that low body condition score (BCS) at calving or a sustained negative trend in ongoing BCS in early lactation would lead to compromised reproductive performance (Loeffler et al, 1999; Walsh et al, 2011; Friggens et al, 2010). This raises a question of sustainability of shorter lactations, several authors

(Inchaisri et al, 2011; Arbel et al, 2001) have indicated that early conception in high yielding cows has a direct effect upon production and reproduction in the subsequent lactation, it may be conjectured that the high average daily production associated with short CI does not give time for re establishment of body reserves prior to commencement of the next lactation. NEB and mobilisation are important factors in the high yields achieved by the Holstein breed, early lactation energy requirements for rapidly increasing production are significantly greater than feed intake can supply at that stage, the energy shortfall is met by body reserve mobilisation (Walsh et al, 2011; Pryce et al, 2004; Roche et al, 2000; Friggens et al, 2010). This would suggest that those calving with low BCS do not have adequate reserve with a resultant negative effect on health and production whilst those that continue mobilising body reserves longer in lactation (into the service period) are partitioning energy towards production over reproduction (Friggens et al, 2010) with a direct effect upon commencement, expression and viability of oestrus. In summary, body reserve mobilisation is an important feature of Holstein breeding allowing them to reach peak yield well before energy intake can match requirements, animals that either calve without sufficient condition to mobilise or those which continue mobilisation longer in lactation are compromised in respect of fertility, due to the energy requirements of milk production this would be closely correlated to higher yielding animals.

In conclusion, there is evidence that reduced reproductive performance and increasing yield level are correlated through mutifactorial cause and effect both direct and indirect. For the UK the introduction of £PLI and a greater focus on practical traits as opposed to type along with direct fertility indices should give rise to a period of sustained improvement in fertility. The observation that many animals achieve optimal reproductive performance (Ouweltjes et al, 1996) clearly indicates that it is both possible to match high production with efficient reproduction but also that there is a bank of available breeding stock that can be used to breed fertility back into the national herd.

For many managers, given the constraints of reproductive performance and the requirements to achieve short lactations as described, early resumption of breeding is used as a management tool with VWP as low as 35 days seen in the national recording database (authors experience). With the outlined counter views in favour of short lactations or in favour of extended, the question is raised as to what length of VWP is optimal given modern genetic traits of persistency and high levels of production? The main objective of this project is to review the economics of rebreeding strategy across a broad range of yield and reproductive performance standards. The authors experience with farmers in the South West of England suggests that many feel that for high yielding animals exhibiting current flatter lactation curves early rebreeding is not economic best practice. Addressing the broad hypothesis “Are current rebreeding strategies optimal given changes in production genetics and nutritional science?” this work will augment and update earlier economic research particularly that of Stott et al (1999) by modelling economic output based upon relevant milk production profiles combined with prevailing economic factors. The results should further inform the question of optimal targets at farm level given the wide range of opinions and practice currently observed, stimulating discussion and raising awareness of optimal fertility targets and standards for the UK. The resultant model may be applied to assess how changes in herd performance could affect farm income. Further refinement would allow use in business support decisions particularly cost benefit analysis for the introduction of high cost capital items for which an anticipated performance improvement can be estimated but not economic returns. Particular areas of note would be heat detection equipment or in line milk analytical tools giving full heat detection and other analytic results.

## 1.4 Review of existing research investigating optimal rebreeding strategy

### 1.4.1 Introduction

To assist in understanding the economics associated with varying lactation length, researchers have enumerated the effects using a range of methods and contextual backgrounds. This review will focus on a selection of papers encompassing different approaches and associated results. The fine detail of the conclusions may not bear direct comparison as most are taken in the context of the region or period in which they are written in so encompass individual and possibly outdated  reasoning (ie quota's, BSE) however certain aspects of the results remain valid as do the methods used.

### 1.4.2 Initial comparison

The review of relevant literature encompassed 6 papers, these were all linked at some level to the general theme of this project however the objectives were not necessarily shared. The conclusions drawn and their context raises an initial point for the review, that is whether it is possible to produce results that can avoid the limitations of industry factors specific to a given timeframe such as quotas (Sørensen and Østergaard, 2003; Inchaisri et al, 2010; Arbel et al, 2001) or the limitations of the specific region  (Sørensen and Østergaard, 2003) such that the work can retain conclusive relevance into the longer term. Clearly the objectives of the papers would lead to the constraints mentioned however it is of note that they all contain strong underlying work which retains current interest when abstracted from the original work. In some instances the results discussed may be considered the converse to those indicated by the production and economic evaluation within the work when reviewed against current production conditions. This was due to the effects of working within a quota regime (Arbel et al, 2001) or against the backdrop of falling cull values in the BSE era (Sørensen and Østergaard, 2003), highlighting why a full review of relevant literature is fundamental; abstracts and discussions published at the time suggest a different outcome to those which would be evaluated in the current production circumstances given the same underlying analysis. These shortfalls are mitigated in varying levels by benchmarking results against one particular output (Meadows et al, 2005; Inchaisri et al, 2011) or expressing as a comparison to the optimal (Stott et al, 1999).

Methodologies across the research were distinct to each author, in respect of individual papers, one group of authors had 2 papers relevant to the study , these were both based upon the same stochastic dynamic model but applied in differing contexts giving both works relevance (Inchaisri et al, 2010 & 2011). High levels of complexity were built into the model, in a parallel with all areas of mathematical modelling if the variables are introduced in order of decreasing significance then there is a balance between increasing complexity and introduced errors against the potential improvement in the model outcome. The author acknowledges the complexity in his work as the model could only be validated by peers using face value validation and rationalism, that is the model looked correct and the output was relevant to the input. The initial paper evaluated "*the economic consequences of reproductive performance in dairy cattle*" by taking three different reproductive performance scenarios then applying a sensitivity analysis to the modelled outcome. This paper, as was recognised by author, demonstrated one the main weaknesses of the concept. If a stochastic model is correctly designed, when run over large numbers of iterations the outcome will reflect the values and distributions upon which the model was built however there were aspects of the results and the discussion that considered the trends introduced within the initial modelling values as opposed to outcomes from the analysis.

The performance tiers upon which the analysis was based were widely differing, the population base and data used for the distributions were Dutch but the poor performance scenario was based upon a CI of 507 days which, in UK terms, would be extremely rare at herd level. The economic impact of reproductive performance at this level would suggest that it would be unacceptable in Holland also, to put this into context the current lower quartile for herd average CI in the UK is 428 days (Hanks and Kossaibati, 2012). Hence it might be considered that the results of the worst case scenario were compromised by the selection of the performance level. Furthermore the use of all poor performance for poor and similarly applied levels for the other two categories reduced value in comparison to practical herd performance where it would be rare to get poor or best performance across all breeding measures, analysis of interaction between the variable levels and a sensitivity analysis within the performance tiers would have offered more insight but these were either not analysed or not reported.

The same stochastic model was applied for evaluation of optimal VWP lengths (Inchaisri et al, 2011), once again using distribution and value ranges from existing research or recording data. The method was to create a model cow given a range of production constraints and apply multiple iterations upon this modelled animal using a range of weekly increases in VWP. The method was applied for various production scenarios and the output was given as a benchmarked comparison with a standard 6 week VWP. This use of the stochastic model and the integration into a wider range of production contexts and benchmarking added value to the model output in comparison to Inchaisri et al (2010). The author indicated that this approach was important as computing optimal VWP from existing records would be difficult due to the unknown reasons for varying lactation length in secondary data. This raises an interesting point as some values included in the original model were based upon NRS (Nederlands Rundvee Syndicate) farm recording data alongside further existing research also including secondary data hence it might be considered that the method may not be insulated from the outlined weaknesses. The concept of taking a baseline result and comparing the modelled results under adjusted circumstances was exactly that used and recommended by Stott et al in the 1999 paper.

Stott et al, (1999) constructed a Markov chain to simulate reproduction events and outcome probabilities then applied different sets of constraints such that the economic effects of increasing days open could be analysed. For each set of constraints the model was run for a maximum equivalent of 20 years by which point a steady state replicating herd performance had been achieved and to this the relevant cost data could be applied for the economic analysis. The combined use of modelling to derive reproductive conditions and application of actual cost data for the economics analysis provides a method which could be reused or replicated under alternative conditions unlike the higher complexity models. It is noteworthy that the probabilities used were derived from the Esslemont and Peeler 1995 analysis of secondary data via the daisy system at Reading so secondary data plays a major role in the mechanics and output of this model.

Meadows et al (2005) took a more simplistic approach in the analysis of the economic effects of varying reproductive performance, one objective being to generate realistic output whilst limiting complexity. An algebraic lactation curve model was applied (Wood, 1967) and input costs and performance characteristics applied from research and secondary data sources reflecting the prevailing performance in Ohio dairy herds. Output was a comparison to a base line cow (445 day CI) to investigate the effects of the differing performance standards in the context of the changing rate of reproduction performance as opposed to purely the economic results.

Arbel et al (2001) avoided the need for complex modelling and the problems of secondary data by evaluating subsets of live animals within individual herds in Israel when researching the effects of extended CI. In comparison to the models of Stott et al (1999) and Inchaisri et al (2010 & 2011) it might be considered that this approach would provide simplicity and be more conclusive. The research analysed results of one full lactation then the first 150 days of the subsequent lactation for animals fitting the criteria of correct production level and calving months. This selection of criteria raises some initial questions, most notably on seasonality. The research indicated that the initial calving dates were chosen to assist in avoiding the effects of heat stress upon production in the research groups, the use of only the first 150 days of the subsequent lactation may also suggest this was to avoid effects of heat stress upon the production analysed. However as extending lactation was the primary research objective it may be considered that shifting calving patterns could move animals to less favourable production conditions as lactations increase, a point which was not addressed within the discussion. Other factors which affected outcome were initial TDY across the treatment and control groups, it was unfortunate that the control groups initial lactation exhibited consistently lower TDY for the first 5 monthly recordings in both primiparous and multiparous animals (tables 3 and 5, Arbel et al, 2001). The average conception days post partum given for these groups would suggest that the yield differentials were unrelated to any effects of gestation but were significant accumulating to around 100kg lower production per animal which, once evaluated economically, accounted for approximately one third of the outcome. A further weakness would appear to be inclusion of records from animals that did not complete a standard initial lactation, depending upon numbers exhibiting this status within the 2 groups there are reasons for negative distortion (ie shorter and hence lower initial lactation totals) or positive bias (longer rest days between lactations), the inclusion of these records looked unlikely to offer any qualitative information apart from maintaining a larger data set. This leads to a situation where the same undesirable weaknesses of secondary data as indicated by the author sets may have been introduced into the analysis of the primary research groups.

The early yield observation from the above paper was included in the modelling used by Sørensen and Østergaard (2003) in the analysis of the economic consequences of delayed first insemination. This paper used a stochastic method to derive reproduction conditions using weekly adjustments of the herd state and then applied actual cost data to the resultant output to complete the economic analysis. The results used the method of benchmarking against the best production for analysis (Stott et al, 1999) but then further analysis in respect of beef values and output applied, this was a research objective in line with falling beef prices due to BSE at the time of the work. The yield analysis was adjusted to reflect the production trends indicated for early service and conception (Arbel et al, 2001). Although, as previously indicated, those figures may have contained some bias against shorter CI, the milk production economic outcomes derived by Sørensen and Østergaard (2003) were converse to those of Arbel et al (2001).

### 1.4.3 Cull cows and production

Deriving relevant values for the significant economic factor of animals completing the final lactation were applied via various methods. Taking average cull rate (34%) in the research data (Meadows et al, 2005) may lead to an output figure that is biased by the averaging effect; although involuntary losses and deaths can occur at any point in lactation and may be considered more likely at parturition and early lactation, most voluntary culls alongside involuntary culls due to infertility could be expected to complete full or extended lactations in some instances. Hence it might be considered that showing a short final lactation is a result of averaging and not a realistic outcome but the economic impacts could be considerable. To mitigate this Meadows et al (2005) applied a method of representing a proportion of full lactation economics to cover the final lactation on a pro rata basis. This would give a complementary approach to using average cull rate such that if the final lactation is estimated to be short then the economic implications noted do not unduly affect results. The author indicated that he assumed culling rates would increase as reproductive performance decreases however counter examples exist. Herds where a policy of applying a maximum breeding threshold would show good performance in respect of days open and CI but high RR whilst herds which continue to serve longer would reduce cull rates to the detriment of CI and days open. This highlights the difficulties in analysing many areas of the subject as rational decisions may not reflect the circumstances or decisions upon which the research data is based.

Inchaisri et al (2011) indicated confounding effects within the analysis due to the model not being optimised for culling decisions but based on fertility culling only. A consequence being that similar culling levels were applied across differing production tiers controlled by reproductive performance with no link between cull and production level. Within the analysis of live animals Arbel et al (2001) found lower than average cull rates in his control and treatment groups which he associated with the selection criteria of *above average performance,* he suggested that farmers were more likely to retain and continue attempting to breed these higher performance animals. This could lead to some bias in the results in comparison to the commercial units where higher RR would be expected. Although the research was based on live cow data he highlighted a further problem in that cull reason information was not available for those that had left the herd due to insufficient record keeping at farm level so analysis of infertility or other cull reasons was not possible.

The markov chain model (Stott et al, 1999) produced a direct output for infertility based culls based upon the reproduction probabilities in the construction and the author applied a further 1% loss rate per month to cover culling for other reasons. The method was robust in that the analysis was based upon only one tier of production (prevailing at the time) and this cull rate was applied to reflect the corresponding average. The higher complexity models calculate culling and applied costs at individual lactation and animal level in each iteration mitigate the need for a corrective final lactation measure such as that applied by Meadows et al (2005).

Cull rates were generated stochastically as part of the *Simherd III* program within the analysis of delaying breeding (Sørensen and Østergaard, 2003). The modelling made an assumption that any cow could be culled and that upon the modelled animal production falling below a threshold yield of 12kg, if the animal was open then she would be culled immediately. This gave an involuntary cull rate of 12-14%, a further feature of this model was that as breeding was delayed and less replacements became available (insufficient for >160 days open) then a cost was applied to equate to purchasing the shortfall thus ensuring that sufficient heifers were available for the model to function with the required number of animals. Meadows et al (2005)took a similar approach to available replacements but the two models differ in that Sørensen and Østergaard (2003) also built in a feature whereby excess heifers would generate revenue if available replicating commercial farming practice.

### 1.4.4 Analysis periods

A further method design question analogous to that of handling final lactations is timing and association of values related to different lactation lengths. If ici is considered to be the unit of measurement then the question is raised (in terms of herd economics) of the associated income for animals with short CI which are economically active in their subsequent lactation while the extended lactation animals are completing late lactation or dry periods. This was a potential problem in the primary research by Arbel et al (2001), taking one full lactation and 150 days in the subsequent lactation for both treatment and control groups would result in the treatment group having 60 more production days in the total evaluation period significantly altering the dry to production day ratio. The author acknowledges the effect on the dry ratio but the results do not represent full lactation analysis and cannot be benchmarked per productive day or per lifetime day.

The stochastic models and the Markov chain (Stott et al, 1999; Inchaisri et al, 2010 and 2011; Sørensen and Østergaard, 2003) take full but varying lactations and compare to a benchmark result, this is a different context as it outputs an optimal result as opposed to financial values for a given lactation length however the lactation production details are extracted to complete the optimisation. By taking primiparous, multiparous and cull animals then the whole productive lifetime of the animal is included so analysis of income per day will give consistent results regardless of the reproductive performance parameters applied.

### 1.4.5 Production standards

In respect of all models analysed the dominant economic factor upon which all subsequent analysis is based is that of milk production. 3 models reviewed use the algebraic curve (Wood, 1967) to derive production levels with the 305 day lactation as the standard comparator.  305 day lactation totals are affected by days open due to the effect of conception upon yield (Lee et al, 1997; Olori et al, 1997), this was enumerated at a maximum of 1613kg for an increase of 250 days open in multiparous animals (Lee et al, 1997). This raises questions about the suitability of using 305 day total as the performance benchmark in evaluation of differing reproductive performance. It might be inferred from the work of Lee et al (1997) that, taking 2 animals with the same 305 day lactation total but 200 days differential in respect of days open, there would be widely differing production characteristics throughout early lactation as the animal with the shorter days open would need higher overall early production levels to counter the effects of conception upon yield, it may be considered that the daily production curves for these two animals are as distinct as their respective reproductive performance hence direct comparison may create difficulties or not be justifiable.

Reviewing Wood's algebraic curve (Wood, 1967) the derivation is of the form;

Yield at day n pp =A × (Days in milk)$^{\mathbf{B}}$ × exp(−C × Days in milk)

where A is a scaling factor related to peak milk in early lactation while B and C are curve shaping parameters that are based on timing of peak yield and persistency. The adaptation of the curve for individual projects involves taking a reference sample base and evaluating the parameters A, B and C such that it can then be used to simulate production within models. We can observe that the parameters A, B and C are constants, this would imply that yield at day n and, logically, cumulative 305 day yield would be the same regardless of the days open in a lactation hence it may be suggested that this model of production has limitations in this field of production research. In respect of modelling the yield differentials as outlined by Lee et al (1997), an option may be to shape curves by a function acting upon days open as opposed to constants for A, B or C but, for the models used by both Inchaisri et al, (2010 and 2011) and Meadows et al (2005) A, B and C were applied as constants and so total output at day 305 would be fixed for all VWP. Clearly the analysis indicated changing *average* daily production but as the lactation lengthens there would be a reduction in average milk output per day and more days of lower production would be included in the overall total hence it is correct that average daily production would decline.

Simherd III (Sørensen and Østergaard, 2003) used a feed capacity based production model which included adjustments derived from previous work (Arbel et al, 2001) to compensate for the effects of later conception so this model did evaluate higher persistency in extended lactations giving variation over differing days open.

The original analysis of specific animal records (Arbel et al, 2001) did not require modelling of production as these were based upon primary data and so, within the methodology described, is not questionable.

Stott et al (1999) evaluated production levels using an integrated model of weight change and production which was attributed to Van Arendonk (1985). The model is outlined below, it is more complex than the algebraic curve (Wood, 1967) including adjustment factors for calving age and month.

$$\mathbf{y_{tl,i,DO} = (a - bt_l - 13exp(-ct_l))(1 + (t_p/140)^2)^{-1} f_m g_i}$$

Where $y_{tl,i,DO}$ = the milk production (kg) at $t_l$ days after calving for the *ith* month of calving and DO days open

a = level parameter (kg)

b = The slope during the decline in production per day after peak (kg per day)

c = parameter describing the initial increase of production

$t_p = t_l - DO - 122$ when $t_l > DO + 121$ and $t_p = 0$ when $t_l < DO + 122$

$f_m$ = effect of the $m^{th}$ calendar month on monthly production

$g_I$ = effect of the $i^{th}$ month of calving on the level of production

As with the algabraic curve (Wood, 1967), the curve parameter setting is done from a reference data set however this function does include an adjustment factor based upon conception date within the model ($t_i$ ). This allows direct adjustment of the curve for conception timing hence it may be considered that this model is more applicable in respect of comparative values of production against costs for increasing days open.

The review of production simulation indicates that certain models for generating lactation curve and accumulated production may have shortfalls in respect of modelling economics of short CI. Many lactation curve and production models have been created since the algebraic curve (Wood, 1967) however the simplicity of the design and accuracy of output across many contexts makes the algebraic curve widely accepted for production modelling across multiple animal species. It may be considered that alternative production modelling is required to maintain performance differentials for economic evaluations of early lactation reproductive performance.

### 1.4.6 Summary

In summary the question of production economics of varied days open or VWP has been reviewed in many contexts due to the fundamental economic importance of the subject. The length of VWP is the only factor in the reproductive cycle that is completely controlled by the herd manager and, as such, presents an opportunity to apply some form of optimal strategy if the relevant decision making data is available. This review indicates that local factors such as quotas, beef price, season of calving and milk pricing structure can all impact upon economics to an extent which may lead to results showing opposing opinions depending upon the context in which they are framed. Furthermore, RR significantly affects herd economics so an optimal figure for VWP is probably unique to every herd within their own local factors and constraints but is arguably unique to every herd member. Optimisation of VWP at that level is impractical as prediction of conception, disease and mortality are not possible, hence the review of local factors and application of an optimal herd level figure for primiparous and multiparous animals is currently the most effective option. It may be considered that as fertility levels improve in the population and female genomic testing becomes more widespread, the availability of fertility factors, production potential, lifetime and persistency traits may make an optimal individual breeding commencement date a practical proposition.

# 2 Methods

## 2.1 Introduction

### 2.1.1 Background

The main objective of this research was to investigate the economics of varying lengths of VWP to assess whether there is an optimal VWP under various management conditions. The main factors for consideration in the model were milk yield, RR, PR, feed costs, replacement costs (and calf income) and length of VWP. Secondary objectives were to compare the importance of other main management parameters (RR, PR) against that of varying VWP using sensitivity analysis. The outcomes would be financial comparators for permutations of different values for each of the latter mentioned parameters to assess their relative importance in respect of overall dairy economics.

The output could be used to aid decisions in respect of which criteria would best improve profitability by either management decision or breeding selection. It is also considered that if fertility continues to improve in the breed then the optimal economic VWP length may change, the sensitivity analysis could be used to investigate this.

### 2.1.2 Model Structure

A major decision was the model type to be used with either stochastic or deterministic being suitable but both having differing qualities. It was felt that stochastic models were best suited to conditions where the modelling criteria were multifactorial but investigating parameters where probability outcomes were more important. These models compile results over multiple runs with the dynamic programming assigning values to the parameter under investigation. Because of the range of parameters being investigated and the use of UK production statistics as opposed to hypothetical changes in management conditions in the modelling, it was decided that a deterministic model would provide the best option for this research.

The use of a deterministic model would give advantages in respect of being able to check modelled outcomes against known outcomes for the industry thus giving a rigorous foundation upon which the sensitivity analysis could be based. These outcomes would then reflect the economic effects of different management practice. The deterministic approach would also be practical for the wide range of parameter changes to be investigated, with 8 yield levels, 3 PR, 4 VWP lengths and 2 RR levels to be applied there would be 192 permutations of performance levels to be compared.

The model would be built in Microsoft Excel, use of individual worksheets for separate sub models of inputs and outputs would reduce complexity and make it easier to check validity of results produced. A final data entry and results sheet could then be used for inputting and results extraction.

A requirement of the model would be to allocate proportional values of inputs and outputs according to the variation in lactation length within the herd. Meadows et al (2005) describes an iterative methodology which was used to produce a partial cash flow for each day of a cow's life. This was applied through use of average milk yield per day of life and economic measures for replacement and culling strategy in combination with feed, breeding and calf values. The variables to be modelled and the methodology for this research are closely related to that work, in particular the use of a single cow as a metaphor for describing herd economics and so the model is based upon similar principles with some novel elements. The premise behind that method is that all elements of herd economic performance are drawn together and combined into ratios representing herd reproductive performance and cull status. The model commences with all animals allocated open status, as the first breeding threshold is reached (end of the VWP) then a proportion are allocated pregnant status and the remainder continue with open status. These calculations are based upon the pregnancy rate, the outlined process is reapplied on an iterative basis using a 21 day interval, hence on the second iteration the animals remaining with open status are proportionally reduced by the pregnancy rate. This approach allocates differing lactation lengths to relevant proportions of the herd by taking the varying lengths of time spent in the open period and combining these with a standard gestation period. A direct result of this is that income and costs can be generated for any lactation length then, in respect of our baseline cow, these can be applied to the relevant proportion associated with that lactation length. So the iterative decay process continues until the entire non cull proportion of the herd is allocated pregnant status. Although the iterative process is completed at this point the output does not represent the entire herd economics as the cull proportion are not included, this is addressed by use of a correction factor based upon dividing the results by 1 minus the cull proportion (where the cull proportion is expressed as a decimal) which then gives the whole herd equivalent. This approach gives the cull element average performance across all parameters, as discussed previously this is considered to be suitable for this model. The result is that the baseline animal represents 100% of the herd based upon proportions set by cull and pregnancy rate with the associated economic factors corrected by varying lactation length. The model for this research varies from that of Meadows in respect of applying yield through bespoke researched UK production modelling as opposed to Woods curve (1969) and also through allocation of half of the cull proportion prior to the first iteration so that the termination of the iterative process is not completed until half of the cull proportion remain with open status.

Storage of the output would be tabular, the results would be analysed in Minitiab 16. This approach would enable investigation of cross variable relationships focussed initially upon VWP and allow financial comparison of the other parameters.

### 2.1.3 Data

A fundamental requirement of the model was to reflect production and economics in the UK at the prevailing time. This gave rise to the following requirements;

i) To model milk production per day of ici- either from existing production models or a model based specifically upon UK production. The use of a large secondary data set would give sufficient data to investigate relationships for the design of a new model or to set the parameters for an existing model.

ii) Reproductive performance- Submission rate, CR (PR) and AI cost per service- This data is widely available however the main data source was the annual KPI study from which relevant reproductive standards were selected (Hanks and Kossaibati, 2012)

iii) Culling rate, cull value, dead rate, dead disposal cost, calf income values- Prevailing market values and the annual KPI study (Hanks and Kossaibati, 2012)

iv) Milk price- Prevailing milk price

v) Feeding cost- These would be based upon information from nutritionists and prevailing feed prices.

## 2.2 Structure of the Model

### 2.2.1 Objectives

The model objective was to generate comparative values for a range of production scenarios reflecting physical and financial conditions in the UK Holstein population in 2011/2. The modelling would be deterministic using financial and physical production parameters relevant to that period. The output values were then used to evaluate the financial implications of varying lengths of VWP and to compare the importance of vwp length against other key economic factors.

Consideration of the output variable was a key initial stage of the process , the model had to simulate different lactation lengths and stages within the herd whilst providing a common output for all parameters analysed. A financial output was most suitable for this so mean income per day of ici (£ici) was selected to give consistent results across all evaluated permutations of performance characteristics. Once a heifer has calved she will spend her life in one of two states, either in an ici or completing the days from final calving until culling. Hence modelling £ici while including suitable allowance for the final lactation production would give the required level of consistency of output as all productive lifetime days are considered. Hence the model may be considered as giving income per day of productive life but, as the parameters included can be subject to continuous change, it could also reflect the state of a herd from given parameter values.

Using a financial output would give results which could be discussed at all levels within the industry. Many farm business run costing systems so income, cost and margin at per cow and per litre level are well understood.

The model would be required to simulate reproduction conditions within any herd. For these reasons it was decided that the model would be based on three different reproductive states;

1) Open- calving to conception

2) Pregnant- commencing at the end of the VWP there would be an iterative decay model based upon 21 day periods. The rate and termination of the decay process would be set by pregnancy and RR. The proportion removed in each iteration are considered pregnant at the mid point of that iteration and their next calving would be 285 days later hence giving the intercalving period.

3) Replacement- proportionate values for the replacement section of the herd would need to be applied. Allaire (1981) indicated that involuntary culls would produce more milk in a year than a cow that is pregnant and completing a 12 month CI. It was also considered that, although many losses occur in early lactation due to parturition and production disorders, a similar proportion of cull cows continue

production well beyond average lactation length in the final lactation. Hence it was decided that a method analogous to that used by Meadows et al (2005) in applying mean performance and cost base for the cull proportion would represent  return value for this portion of a herd.

The three stages of the herd analysis outlined are mutually exclusive but contain the complete herd at any given point in the modelling process.

This iterative approach would facilitate financial outputs for each iteration of the decay model for the complete herd which could then be accumulated using a proportional summation to give an overall herd figure.

With the output variable and modelling method selected, the final objective would be to run the model over multiple permutations of varying input parameter values such that data could be collected which would allow sensitivity analysis based upon a range of production and lifetime values alongside breeding performance decisions. This output would form the basis of the results and discussion allowing direct comparison of the importance of the various input scenarios to individual production systems.

### 2.2.2 Parameters for evaluation

The second stage of the modelling process was consideration of variables for inclusion in the model alongside the parameters to be evaluated in the sensitivity analysis. As the model was to be applied in Microsoft Excel  (Microsoft TM) the model could be simplified into a set of sub models each calculating values for specific inputs or outputs  for compilation into summary results for each permutation.

The sensitivity analysis was to include VWP, PR, test day weight and RR, to model these accurately a range of further variables would be required to reflect the relevant physical and financial conditions. Although these additional variables would not be amended in the sensitivity analysis,  applying them as variables within the model would allow for wider application of the model or appraisal of different parameters if required. Table 1 shows the relationship of the main parameters to each  sub-model and the additional variables for consideration in each;

| **Calf value** | | |
|---|---|---|
| RR | Replacement rate | % |
| £HFF | Holstein heifer calf value | £ |
| £HFM | Holstein bull calf value | £ |
| £BF | Beef Heifer calf value | £ |
| £BM | Beef bull calf value | £ |

| **Replacement cost** | | |
|---|---|---|
| RR | Replacement rate | % |
| DR | On farm death rate | % |
| HV | Heifer purchase price | £ |
| CCV | Cull cow value | £ |
| Dead | Dead removal cost | £ |

| **Feed costs per day** | | |
|---|---|---|
| VWP | VWP | Days |
| PR | Pregnancy rate | % |
| TDY | Test day yield | kg |
| ELM | Early lact maintenance | £ |
| ELL | Early lactation per kg | £ |
| MLM | Mid lact maintenance | £ |
| MLL | Mid lactation per kg | £ |
| DRY | Dry maintenance | £ |
| DP | Dry period length | days |
| EMC | Change early to mid | days pp |
| RR | Replacement rate | % |

| Milk yield per day | | |
|---|---|---|
| VWP | VWP | Days |
| PR | Pregnancy rate | % |
| TDY | Test day yield | kg |
| MP | Milk price | £ |
| RR | Replacement rate | % |

| Insemination costs | | |
|---|---|---|
| RR | Replacement rate | % |
| PR | Pregnancy rate | % |
| AI | Insemination cost per service | £ |

Table 1 Variables included in each sub-model

Although fertility intervention and breeding program costs were considered as important to the overall model, no existing methods of allocation of costs on a production basis were found to include in the model. Anecdotal evidence suggests that as herd production levels increase there is an associated increase in fertility intervention costs but, without either existing work to reference or farm based cost records with suitable rigour for analysis, it was decided that this area would not be included in the model. A stochastic model may have been advantageous by generating estimations for intervention and associated costs however suitable background details would have still been required. Groenendaal et al (2004) quoted a flat rate cost application where costs were allocated on a flat rate for the first lactation with incremental increases thereafter. This approach would have added very little qualitative information for this analysis as the $5 increase per lactation indicated would have little impact upon the model output relative to the main cost bases analysed.

### 2.2.3 The Iterative Model

As indicated in 2.1.2, the results are to be expressed in respect of a single animal representing herd performance with the model simulating production and costs reflecting the state of milking herds given set conditions. This approach allows sensitivity analysis assessing the impact of change in various management parameters within the deterministic model. It was decided that an iterative function would allow the division of the herd into cohorts set by status or gestation stage. Meadows et al (2005) modelling methodology and this model concept were described in 2.1.2, for each 21 day iteration the relevant proportion would be allocated pregnant status and for these bespoke income and costs generated for the associated CI. These results would then be proportionally represented within the cow metaphor and analysis based upon the accumulated economic and production factors for the given characteristics of production and reproduction performance.

The model would require 3 parameters for this process;

VWP- Animals would be considered open throughout VWP

PR % (PR%)- The product of cows eligible for service and CR, a model assumption is that the open proportion of the herd would decay by this rate on each 21 day iteration.

RR% (RR%)- The iterative process would terminate upon reaching a bound set by RR. The replacement proportion is allocated financial status in each iteration by multiplying the results by 1 + (cull % / 100). This assumption is based upon the mean low volumes of production achieved by involuntary culls averaged against the relevant production for voluntary culls that complete extended lactations. Individual herd performance in respect of voluntary and involuntary culls is sufficiently varied for this assumption to be acceptable.

It was considered that commencing with 100% open and terminating the iterative process at the RR threshold would not suitably reflect actual herd scenarios by giving too few iterations for the model to be representative (the mathematical reason for this is shown in Appendix 5.2). Taking into account that voluntary culls should not be considered part of the breeding herd and that a proportion of losses occur early in lactation it was decided that half of the RR would be removed from the breeding herd prior to iteration 1 with termination when half of the RR remains open. This would give a more representative number of iterations across all RR in the modelling improving the accuracy of the simulation.

The model commences at day 0 (parturition), the first iteration is applied at VWP + 10.5 days (replicating the mid point of the oestrus cycle following the end of the VWP) and the non pregnant or *open* herd decays by PR on iteration 1. The β and δ models (below) calculate the proportion of the herd conceiving in each iteration. Hence the open herd will continue to decay by PR on a 21 day basis until the lower bound of half of the RR is reached, the last iteration to be adjusted to fit that variable. The β and δ models are used in many aspects of the wider model most notably in milk production however they are also used to calculate a simulated ici which has wider application in the feed, replacement and calf value calculations.

<u>The iteration function</u>

For purpose of the modelling and consistency, the iteration function is most practically applied as 4 separate components;

Firstly a control function for the number of iterations occurring for the given RR. As described, the main iterative approach commences with the total 100 – 0.5 x RR, then decays on each iteration by the PR, PR. The value calculated by each iteration is the differential between 2 consecutive totals after the decay has been applied. The final iteration has to be adjusted so that the lower bound of 0.5 x RR is not exceeded and that the summation of all decay and the RR is 100% as required. Applying these specifications and denoting the control function as $\alpha$, this function calculates the number of complete iterations occurring without exceeding the lower bound,

$$\alpha = \mathrm{floor}\left[\frac{\ln\left[\dfrac{\mathrm{RR}}{(200-\mathrm{RR})}\right]}{\ln\left[1-\left(\dfrac{\mathrm{PR}}{100}\right)\right]}\right]-1$$

A function to calculate the proportion of animals conceiving in each iteration is defined from above using RR and PR. This would be applied within summations to calculate the costs or production levels attained by the relevant proportion of the herd, this function is denoted $\beta$,

$$\beta(\mathrm{RR},\mathrm{PR},n) = \left[100-\left(\frac{\mathrm{RR}}{2}\right)\right]\left(1-\frac{\mathrm{PR}}{100}\right)^{n}-\left[100-\left(\frac{\mathrm{RR}}{2}\right)\right]\left(1-\frac{\mathrm{PR}}{100}\right)^{n+1} \quad \text{where } n = 0,1,..,\alpha$$

The third function calculates the proportion of animals included in the final decay such that the lower bound of 0.5 times the RR is not exceeded, this would use RR and PR and is denoted $\delta$,

$$\delta(\text{RR},\text{PR},\alpha) = \left[100-\left(\frac{\text{RR}}{2}\right)\right]\left(1-\frac{\text{PR}}{100}\right)^{\alpha+1}-\frac{\text{RR}}{2}$$

The final function calculates average ici given the parameters VWP, RR and PR. This is defined from the previous functions, the scaling factor 1/(100 – RR) is included to adjust for the RR. This function is denoted $\Omega$,

$$\Omega = \frac{1}{100-\text{RR}}\left[\left(\sum_{n=0}^{\alpha}\beta(\text{VWP}+285+10.5+21n)\right)+\delta(\text{VWP}+285+10.5+21\alpha)\right]$$

## 2.3 Replacement, Disposal and Calf Income sub model

### 2.3.1 Background

Replacement costs are a major source of cost within the UK dairy Industry. The 2012 500 herd KPI study (Hanks and Kossaibati, 2012) indicated that the median number of lactations completed per animal was 3.8 which equates to a RR of 28%. Taking average values of £1750 for a replacement heifer and a cull income of £400 this translates to £315 replacement cost per lactation for median herds suggesting that 50% of all UK herds incur replacement costs in excess of £315 per lactation.

In a 2011 review of dairy farming (FBS, 2011) annual herd replacement costs were quoted between £279 and £191 per animal. Taking the median calving index to be 414 days (Hanks and Kossaibati, 2012) and factoring these figures gives pro rata lactation replacement costs between £307 and £210 per lactation. The two sets of research indicate that 50% of UK herds probably incur replacement costs in excess of £300 per lactation however with many units breeding their own replacements these may not be seen as tangible costs.

Taking average yield to be 8868kg (CDI, 2012) and average prevailing milk price of c27ppl (Hawkins, 2011) and 3.8 lactations per animal would suggest that replacement costs equate to around 3.5ppl or 10-15% of production income per lactation. Previous work on RR has shown that the variation in home rearing costs versus purchased replacements combined with the fluctuation in market values for both replacements and culls make this area dynamic so no figure could be quoted as optimal. Allaire (1981) suggested that 1-3 animals per 100 should be replaced to optimise the benefit of improved genetics, higher levels would be uneconomic through increased rearing costs and reduced multiparous animals in the herd. Kalantari et al (2010) suggested that optimal culling rates were in excess of 30% , however of this a maximum of 3% would be voluntary culling in line with the previous work by Allaire (1981). The indication of a payback for improved genetics against higher replacement cost is positive but of a low order suggesting that reducing involuntary cull rates would decrease costs in the industry whilst not affecting rates of genetic improvement.

### 2.3.2 The Replacement, Disposal and Calf income model design and output

Taking 3% as an optimal voluntary cull rate then overall RR would be governed by involuntary culls, non selection would indicate random distribution across the age and genetic merit distribution of the herd. Assuming that any improved income generated from enhanced genetics would be the same regardless of cull rate it follows that, in a deterministic model, there is no value in inclusion within the model as the overall contribution would be the same for all management profiles under analysis.

Hence, taking the variable definitions as described previously, the replacement cost model calculation for generating income per day of ici (ici) would be;

$$\frac{(\mathrm{RR} - \mathrm{DR})\ \mathrm{CCV} - \mathrm{DR\ DEAD} - \mathrm{RR\ HV}}{100\ \Omega}$$

For calf income, taking RR and an additional 10% of RR(allowing for losses from birth to herd entry) as the number of heifers required and applying an assumption of 50% heifer to bull ratio, the proportion of animals pregnant to Holstein would be 2.2 times the RR. Applying an assumption that any remaining pregnancies would be to beef breeds allows completion of the calf income model to be expressed as mean cost per day ici.

$$\frac{1.1\ \mathrm{RR}(\pounds\mathrm{HF} + \pounds\mathrm{HM}) + (50 - 1.1\ \mathrm{RR})\ (\pounds\mathrm{BF} + \pounds\mathrm{BM})}{100\ \Omega}$$

## 2.4 The Production Model

### 2.4.1 Background

The fundamental requirement for production simulation is prediction of lactation total and mean daily production. Accurate prediction of expected daily yield or modelled lactation curves derived from parametric values output from most current production models would offer no advantage for this analysis. Whilst the incomplete gamma (IG) function (Wood, 1967) continues to be widely used in research projects as a predictor of daily yield and total lactation, many alternative methods have been published since based on methods of setting parameter values from existing data which are then extrapolated to a wider population base. The proliferation of models serves to highlight a problem in that the parameters can be set to accurately fit the research data to which they are applied but lose accuracy when applied under different production conditions. Adediran et al (2012) demonstrated this with a comparative analysis of 14 models including their own research derived log-quadratic model which was designed to model the inconsistent lactation profile exhibited in grass based systems in South Australia. The new model most accurately reflected the actual data profile to which it was compared whilst the incomplete gamma function (Wood, 1967) was shown to give the greatest residuals when applied to the modelled data set. The incomplete gamma model however continues to be accepted as a standard across the scientific community suggesting that it retains suitable accuracy over the wider population to satisfy research demands. The comparison (Adediran et al, 2012) highlights the variation in international production conditions and their effect on prediction methodologies illustrating that no one model proposed thus far can be used universally , it may be conjectured that the wide ranging physical conditions and production limitations exhibited across different countries means that specific models for given conditions will always provide greater accuracy than a universal model.

The inconsistencies of the previous prediction methodologies within various specified contexts as reviewed above raises questions about their suitability for application within the current work. It is considered that the complexity of existing models may be unnecessary as estimation of daily yield is not required, although integration of curve generation models could provide total lactation production, the suitability of each model to the population under review would need rigorous analysis. Hence it was decided to implement an in depth analysis of existing records with the objective of assessing whether an alternative model could be designed. Interrogation of a national data set to gain insight on mean total and mean daily production in relation to TDY data and lactation length could establish such a relationship. This data interrogation would either give the basis for a simplified model or be used to set parameter values for application in existing models.

The choices available for this analysis were either meta data interrogation with the objective of a simplified model based upon the two parameters outlined or a more comprehensive analysis based upon BLUP principles. The single biggest weakness applicable to either methodology would be that of assigning a reference value for the comparative levels of production. As outlined previously, taking 305 day yield as a production comparator for analysis of days open would give bias in the analysis leading to unsuitable results. BLUP principles would allow total lactation production and lactation length to be the basis for comparison however this would lead to a complex recursive model where the reference value for production level comparison would change as parameter values are adjusted in the sensitivity analysis. This difficulty could be overcome by producing reference tables of comparative results analogous to the method used by Stott and Kennedy (1993) in their analysis of the effects of mastitis control and culling on dairy economics. For that model two reference data sets of comparative yields were generated depending upon state variables of lactation and whether infection had occurred. The BLUP analysis was used to develop total production values depending upon the mastitis infection status and lactation number but the output yield reference data was strictly based upon an average output leading to just 24 lactation total values. For this research the combination of changing VWP, RR, PR and production value would require a significantly larger output reference data set, further to this the data quantities available for any given set of parameters would be considerably reduced as the total data set would be divided into multiple analysis sets representing each permutation of the variables. Any completed model on this basis would be discrete and restricted to the values assigned in the initial BLUP analysis where an objective of this project is to develop a model that can be used to assess the effects of small increments in any parameter. To achieve this a continuous model of production with a fixed value reference point would offer significant advantage allowing adjustment of the main variables whilst retaining the simplicity of a given production reference point. Hence it was decided that if a suitable simplified continuous model could be derived based upon the reference point of an early lactation test day yield then this would offer the greatest flexibility in respect of the wider model.

The required output from the production modelling was natural lactation total and the variables included were *test day yield* (TDY) and *inter calving interval* (ici). Mean milk production per day of the ici (M ici) can be derived from lactation total as the quotient of modelled lactation total (kg) and ici (days).

Thus phase one of the data analysis was to assess whether a significant correlation could be derived for natural lactation total from the value of a single TDY occurring within a specific set of days post partum for a given lactation length. Danell (1982) indicated that the later in lactation a TDY was taken, the stronger the correlation between lactation total and the test day weight, Lee (1997) indicated that, for cows with a given production capacity, differing 305 day lactation totals were recorded due to the effects of gestation upon yield. In a study of the effects of gestation upon yield , early conception had a proportionally greater effect upon 305 day yield than later conception suggesting a direct effect of conception on daily yield which decreasing importance as conception occurs later (Olori et al, 1997). It is logical that the proportion of pregnant cows will increase with increasing days pp, the work of Olori et al (1997) suggests that to achieve consistency between TDY and total lactation, the window of TDY data should be early in lactation to mitigate the effects of variations in fertility status. It could be considered that only when cows are in a similar reproductive state could TDY be used as an indicator of potential production, early lactation TDY data should be unaffected by gestation. Accepting both this observation and the work by Danell (1982) it was considered that a compromise between the effects of gestation on later lactation TDY and the increasing accuracy of later weighings in predicting lactation total would be required to achieve the model outcomes.

Given sufficient TDY data, regression analysis of data grouped by TDY cohorts using ici as the independent variable and natural lactation as the dependent could be used to investigate for a relationship. This analysis would require sufficient data to minimise effects of localised production conditions and reduce individual herd effects. It was considered that secondary data from a UK MRO would be most suitable for the analysis given the scale of the data sets available. The advantages of scale are countered by the variable quality of data as indicated by Pryce et al (2000), however widely published data filtering, event handling procedures and cleaning methods can be applied to mitigate these weaknesses.

### 2.4.2 Materials and Methods (Phase one)

A data set (n=435180 records) was obtained from National Milk Records plc including all Holstein animals completing lactations between 1/6/2012 and 31/5/2013, this data had no pre-selections applied and was assumed to be representative of all UK production systems and genetic profiles. Microsoft Excel was used to apply initial cleaning to the primary data set. An initial restriction was applied to exclude all animals without a subsequent calving date as this was a requirement to calculate conception days pp. The quality of service data available from recording schemes is variable (Pryce et al, 2000) and conception dates are poorly recorded. Applying a count back of days from the subsequent calving date using a standard gestation period of 285 days would provide a suitable proxy for conception date for the requirements of this research. This restriction would also remove lactations affected by death or sales (Mackey et al, 2007) improving overall validity. Further cleaning and filtering methods which were applied to this specific research were based upon Ouweltjes et al (1996) and Albarrán-Portillo and Pollott (2013) , including;

The removal of non qualifying lactations by ICAR rules

First calving must occur between 18 and 48 months of age

Accepting multiparous animals only with a maximum of 8 completed lactations

Excluding records where conception occurred earlier than day 30pp

Including lactations with a minimum of 6 test day weighings

Removal of long (>495 days) lactations as these were not relevant to this research.

The resulting data (n= 376624 records) were exported to Minitab 16 (Minitab inc) for the main analysis. Each record was allocated into 2 distinct sets of cohorts, one set by test weighing date (measured in days post partum (5 day windows commencing at day 10)) and the second by ici (10 day windows commencing at 315 days). The data were analysed on permutations of the cohort groups, initially divided into test day weighing date (TDWD) cohorts then each TDWD cohort was subdivided into the ici cohorts. The regression analysis was applied with TDY as the independent variable and dependent variable natural lactation total.

### 2.4.3 Results (phase one)

A total of 376624 records were used in the initial data analysis, enabling comparative analysis across 99 permutations of the TDWD (days pp) and lactation length cohorts with n > 400 in each analysis. Linear, quadratic and cubic regression were tested, linear was most consistent across the permutations, the results summary for the TDY (by days post partum) cohorts are shown in the Table 2 analysis, Table 3 shows a subset of the overall results with regression groups based upon ici, Figure 1 indicates the relationship for one cohort in the given analysis.

| Test Day Weighing (days pp) cohort | n | Weighted ave R-sq |
|---|---|---|
| 10-15 days | 11914 | 32.67 |
| 15-20 days | 12559 | 42.01 |
| 20-25 days | 12475 | 48.49 |
| 25-30 days | 12988 | 52.82 |
| 30-35 days | 12748 | 55.01 |
| 35-40 days | 13079 | 57.27 |
| 40-45 days | 13157 | 58.11 |
| 45-50 days | 13003 | 60.99 |
| 50-55 days | 13028 | 62.3 |
| 55-60 days | 11277 | 63.25 |

Table 2- The summary results for the linear regression based upon test day weighing cohort.

| Test Day Weighing Window (days pp) | lci cohort | regression coefficient | regression constant | R-sq | n | Test day yield cohort summary | |
|---|---|---|---|---|---|---|---|
| days 50-55 | 315-325 | 185.9 | 953 | 70.7 | 449 | | |
| days 50-55 | 335-345 | 185.9 | 1356 | 68.9 | 1872 | | |
| days 50-55 | 355-365 | 189.1 | 1589 | 64.9 | 2277 | | |
| days 50-55 | 375-385 | 199.8 | 1677 | 66.2 | 2268 | | |
| days 50-55 | 395-405 | 197.9 | 2078 | 59.4 | 1801 | | |
| days 50-55 | 415-425 | 205.1 | 2185 | 62 | 1418 | | |
| days 50-55 | 435-445 | 198.1 | 2847 | 54.3 | 1213 | | |
| days 50-55 | 455-465 | 207.5 | 2725 | 54.6 | 973 | Total n | 13028 |
| days 50-55 | 475-485 | 196.8 | 3644 | 51.7 | 757 | Weighted ave R-sq | 62.3 |
| days 55-60 | 315-325 | 193.3 | 748 | 76.2 | 451 | | |
| days 55-60 | 335-345 | 193.5 | 1193 | 70.5 | 1809 | | |
| days 55-60 | 355-365 | 189.1 | 1690 | 67 | 2160 | | |
| days 55-60 | 375-385 | 199.7 | 1674 | 65.3 | 2122 | | |
| days 55-60 | 395-405 | 199.9 | 2051 | 61.2 | 1794 | | |
| days 55-60 | 415-425 | 205.8 | 2162 | 60.2 | 1516 | | |
| days 55-60 | 435-445 | 207.6 | 2490 | 57.3 | 1198 | | |
| days 55-60 | 455-465 | 204.3 | 2899 | 53.1 | 908 | Total n | 12685 |
| days 55-60 | 475-485 | 208.2 | 3131 | 53.9 | 727 | Weighted ave R-sq | 63.25 |

Table 3 Results for the regression analysis of 2 TDY cohorts subdivided into 9 lactation length cohorts

Table 3 indicates increasing r-squared as TDY are recorded later in lactation. This result is in agreement with the observations of Danell (1982), it could be suggested this relationship may continue to strengthen as TDY are taken later in lactation but , in this context, an early lactation TDY would be required to mitigate the effects of early conception on yield (Olori et al, 1997; Philipsson, 1981).

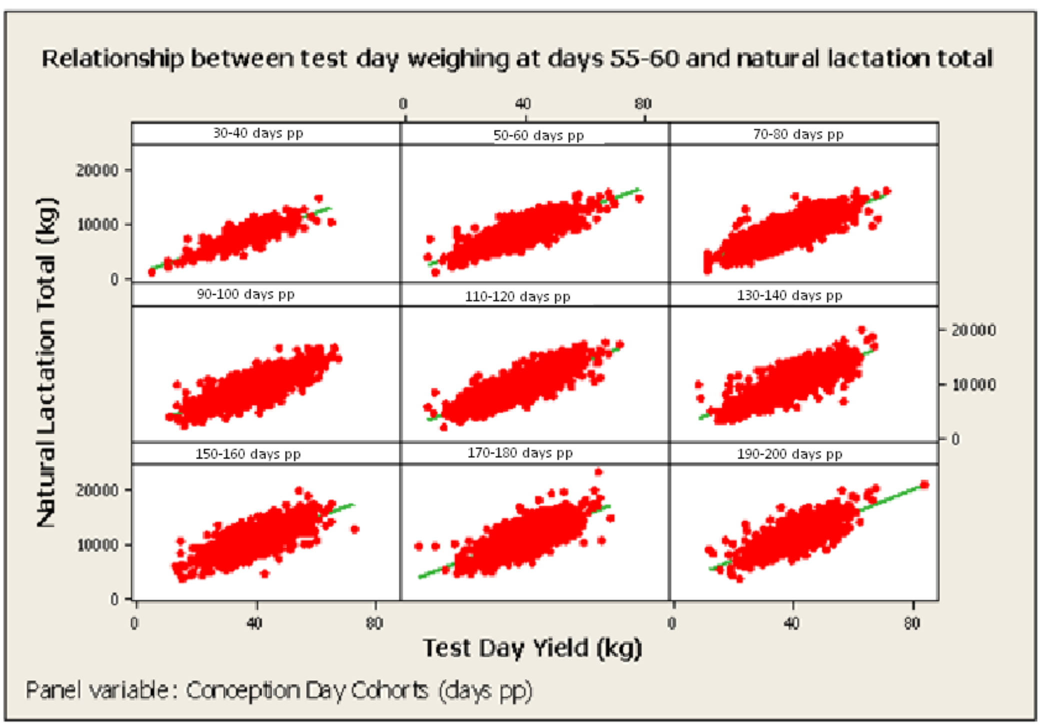



Figure 1 Linear regression graphs indicating the relationship between a single test day weighing between days 55-60 and natural lactation total with each panel representing a cohort

The results shown in Table 3 and Figure 1 show reducing r-squared with later conception indicating a weakening of the relationship between the single TDY and natural lactation with increasing lactation length. This may be a consequence of increasing probability of a yield impact event with increasing lactation length affecting the range of lactation totals for later conceiving animals with comparable milk weights at a given test day weighing.

The results suggest that TDY taken between days 50 and 60 pp could be used to indicate natural lactation total given ici. Any model based upon TDY and ici would become less reliable as lactation length increases. It should be noted that results for any model of lactation total would suffer similar effects as lactation length increases when compared directly with actual results from a large sample

### 2.4.4 Materials and methods (phase two)

Using Minitab 16, additional filtering was applied to the main data set such that only records of animals with a test day weighing occurring between days 50 and 60 pp were included (n = 47378). Each record was allocated to a cohort based upon TDY and ici, mean natural lactation was then calculated for each cohort group. These results were plotted with the independent variable ici against the dependent variable *natural lactation total* , best fit lines were added for each TDY cohort and the resultant output used to establish whether a suitable model could be derived.

### 2.4.5 Results (phase two)

| ici | TDY | 15 | 21 | 27 | 33 | 39 | 45 | 51 | 57 | 63 | 69 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 320 | Data means | 4637 | 5145 | 6311 | 7339 | 8493 | 9466 | 10551 | 11249 | 11904 | 12343 |
| 330 | | 4722 | 5609 | 6575 | 7570 | 8677 | 9595 | 10708 | 11617 | 12959 | 13299 |
| 340 | | 5249 | 5807 | 6762 | 7830 | 8874 | 9921 | 10944 | 11992 | 12960 | 13825 |
| 350 | | 5452 | 6036 | 6980 | 7989 | 9060 | 10077 | 11177 | 12187 | 12946 | 13542 |
| 360 | | 5600 | 6212 | 7125 | 8173 | 9258 | 10287 | 11371 | 12364 | 13334 | 13781 |
| 370 | | 5733 | 6412 | 7334 | 8351 | 9444 | 10558 | 11616 | 12695 | 13555 | 13355 |
| 380 | | 6170 | 6528 | 7514 | 8517 | 9695 | 10789 | 11822 | 12973 | 14215 | 13941 |
| 390 | | 6170 | 6767 | 7686 | 8816 | 9921 | 10982 | 12018 | 13182 | 14091 | 15351 |
| 400 | | 6132 | 7027 | 7914 | 8949 | 10075 | 11172 | 12369 | 13285 | 14327 | 15476 |
| 410 | | 6423 | 7098 | 8121 | 9129 | 10269 | 11381 | 12587 | 13816 | 14550 | 16020 |
| 420 | | 6668 | 7223 | 8214 | 9280 | 10433 | 11577 | 12660 | 13774 | 14758 | 16546 |
| 430 | | 7287 | 7504 | 8477 | 9514 | 10640 | 11774 | 12995 | 14131 | 15390 | 16158 |
| 440 | | 7022 | 7579 | 8694 | 9685 | 10777 | 11985 | 13036 | 14039 | 15288 | 15735 |
| 450 | | 7312 | 7740 | 8759 | 9993 | 11049 | 12143 | 13256 | 14453 | 16097 | 16382 |
| 460 | | 7342 | 8139 | 8917 | 9981 | 11165 | 12261 | 13402 | 14567 | 16342 | 16323 |
| 470 | | 7590 | 8052 | 9049 | 10197 | 11311 | 12493 | 13744 | 14803 | 15479 | 16160 |
| 480 | | 8177 | 8418 | 9332 | 10363 | 11455 | 12675 | 13699 | 14810 | 16587 | 17357 |

Table 4 Mean natural lactation across the cohorts

Table 4 shows mean natural lactation data for each cohort, Figure 2 shows the output of this analysis in graph form. These results would suggest that a linear model could be used to predict total lactation from the 2 variables, there is increasing divergence towards the extrema of the conception days range and at the highest and lowest yield levels however these regions contain much smaller sample sets with corresponding increased standard deviations.

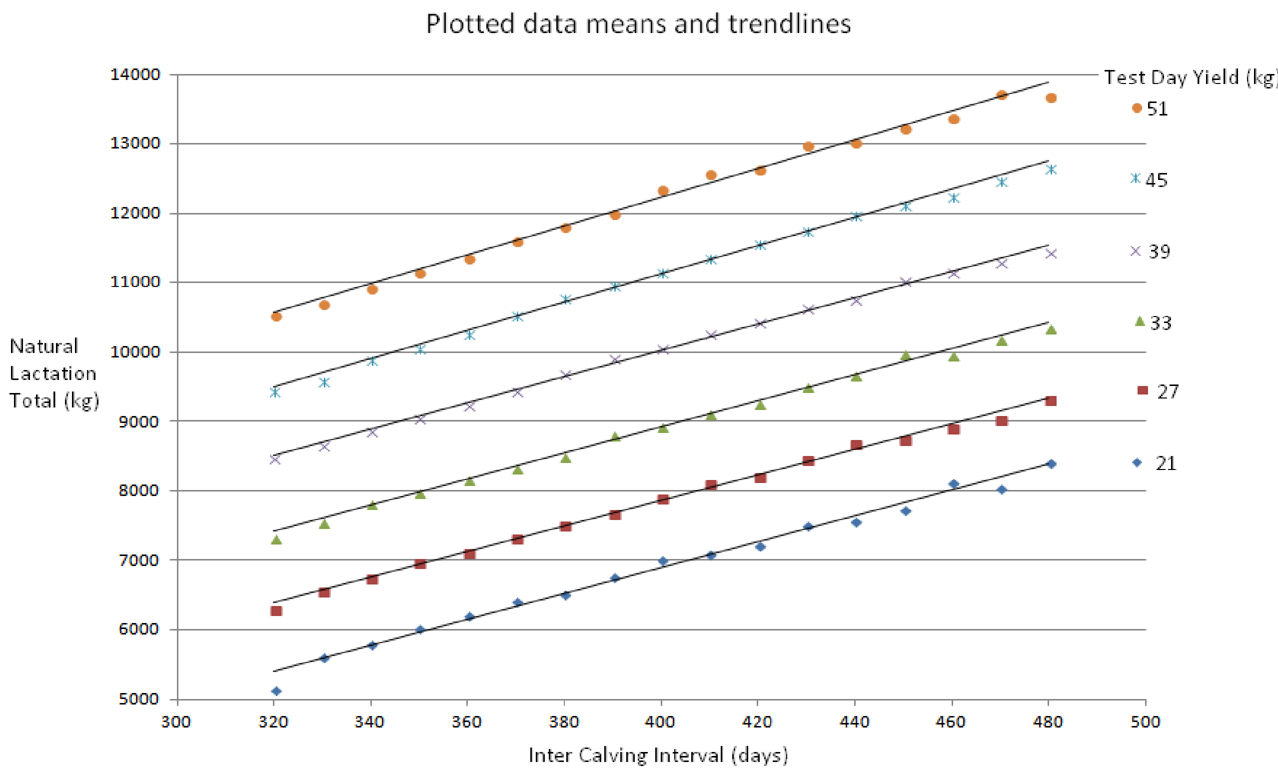



Figure 2 Plotted mean lactation total for TDY cohorts- the data points indicate the mean lactation totals and illustrate the relationship between conception days pp and mean natural lactation total.

The model could take the form $y = mx + c$ however both the intercept and gradient values are variable and influenced TDY. Hence the expected model would take the form;

Total lactation = $f_1$(TDY, ici)+ $f_2$ (TDY )+K, where;

(i) $f_1$*(TDY, ici)* sets the gradient of the line

(ii) $f_2$ *(TDY )+K* sets the intercept value.

Upon division by L this model could also be used to estimate mean milk produced per day ici.

To model the intercept values, the regression constant values for each line in Figure 2 were plotted with TDY as the independent variable and regression value as the dependent as shown in Figure 3. It was apparent that a linear relationship would be suitable to model these values. The resultant gradient (130.9) of this line indicates the increase in intercept value for each kg increase in TDY. The constant value of -3150 was derived by minimising the residual between modelled intercept and actual intercept values. Hence for the lactation production model, the intercept values for the model are given by;

Intercept value = 130.9TDY – 3150

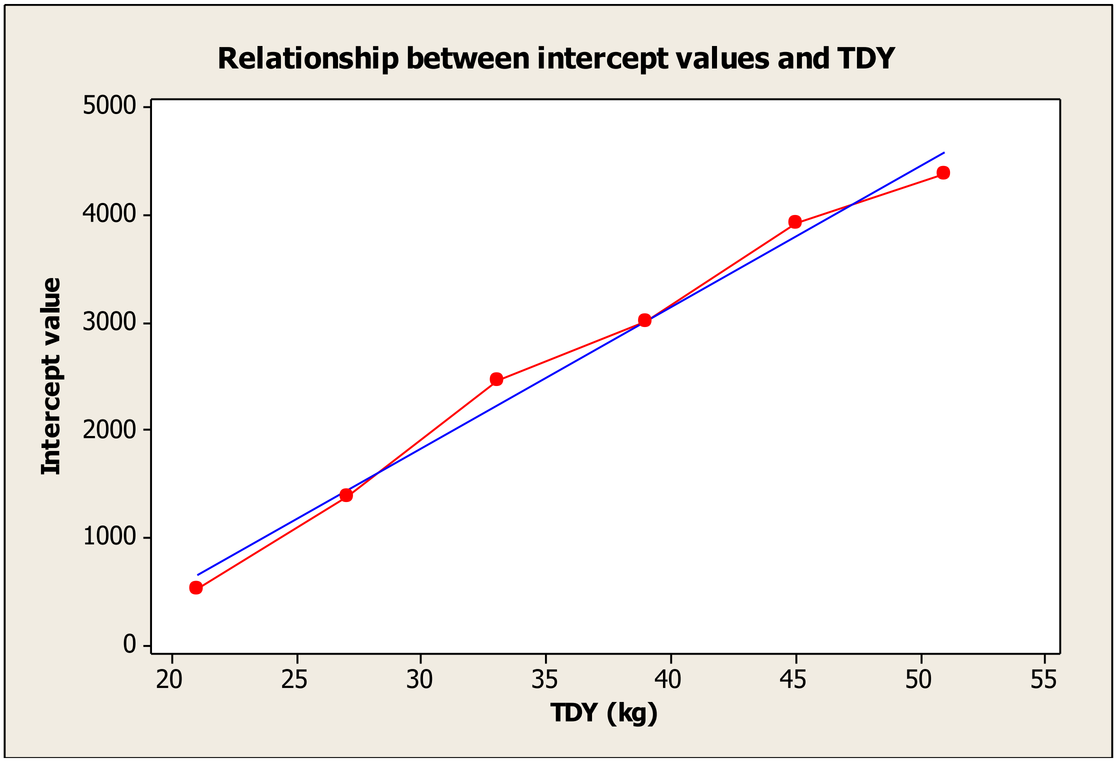



Figure 3 The linear relationship between increasing TDY and the intercept values for the total lactation model. The blue trace shows the regression fit against the data points (Red)

The second phase was to derive the gradient function. For any fixed TDY, the relationship between total lactation and ici was linear however the gradient for each cohort (Figure 2) increased with increasing TDY. The same approach to that used for deriving intercept values was applied but, for modelling the slope, it was observed that a quadratic function on TDY was most suitable (Figure 4).

The resultant equation for the gradients was given by

Gradient = $19.22-0.1074TDY+0.003249TDY^2$

Hence the equation for lactation total given a TDY between days 50 to 60pp and ici is modelled by;

Lactation total (kg) = $(19.22-0.1074TDY+0.003249TDY^2)ici + 130.9TDY - 3200$

This can also be used to model milk per day of ici on division by ici giving

M ici = $19.22-0.1074TDY+0.003249TDY^2 + (130.9TDY - 3200)/ici$

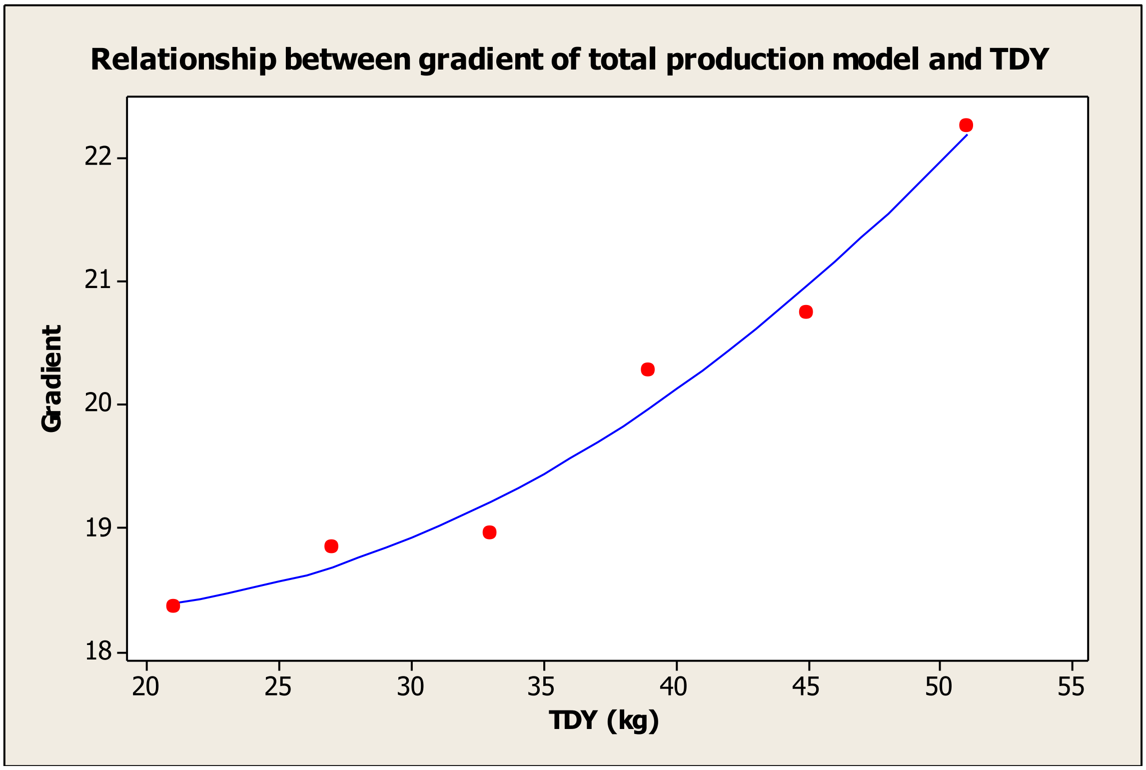



Figure 4 The quadratic relationship between increasing TDY and the gradients required for the total lactation model

| L | T | 15 | 21 | 27 | 33 | 39 | 45 | 51 | 57 | 63 | 69 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 320 | Model results minus data means error percentage | 0.54% | -4.98% | 0.67% | 1.71% | 3.12% | 1.54% | 0.72% | -4.08% | -9.16% | -16.72% |
| 330 | | -1.48% | 0.46% | 1.83% | 2.30% | 2.98% | 0.86% | 0.17% | -2.73% | -2.23% | -10.00% |
| 340 | | 5.32% | 0.78% | 1.89% | 3.14% | 2.94% | 2.07% | 0.38% | -1.43% | -4.25% | -7.95% |
| 350 | | 5.48% | 1.54% | 2.35% | 2.73% | 2.81% | 1.55% | 0.55% | -1.71% | -6.20% | -11.97% |
| 360 | | 4.73% | 1.37% | 1.70% | 2.55% | 2.70% | 1.52% | 0.30% | -2.10% | -4.81% | -12.24% |
| 370 | | 3.77% | 1.56% | 1.93% | 2.33% | 2.53% | 2.07% | 0.45% | -1.35% | -5.17% | -17.76% |
| 380 | | 7.66% | 0.51% | 1.84% | 1.99% | 2.99% | 2.20% | 0.28% | -1.11% | -2.16% | -15.01% |
| 390 | | 4.71% | 1.32% | 1.62% | 3.12% | 3.17% | 2.01% | 0.12% | -1.24% | -4.91% | -5.79% |
| 400 | | 1.15% | 2.34% | 2.08% | 2.45% | 2.68% | 1.79% | 1.12% | -2.26% | -4.70% | -6.94% |
| 410 | | 2.71% | 0.76% | 2.30% | 2.24% | 2.57% | 1.76% | 1.07% | -0.02% | -4.98% | -5.11% |
| 420 | | 3.55% | -0.10% | 1.10% | 1.76% | 2.19% | 1.61% | -0.18% | -2.05% | -5.23% | -3.29% |
| 430 | | 9.26% | 1.27% | 1.98% | 2.15% | 2.18% | 1.45% | 0.76% | -1.16% | -2.55% | -7.49% |
| 440 | | 3.33% | -0.21% | 2.24% | 1.86% | 1.59% | 1.44% | -0.66% | -3.55% | -4.97% | -12.63% |
| 450 | | 4.57% | -0.53% | 0.83% | 2.98% | 2.19% | 0.98% | -0.69% | -2.24% | -1.31% | -9.32% |
| 460 | | 2.50% | 2.15% | 0.55% | 0.94% | 1.41% | 0.25% | -1.22% | -2.99% | -1.34% | -11.48% |
| 470 | | 3.20% | -1.19% | -0.06% | 1.17% | 0.92% | 0.36% | -0.35% | -3.01% | -8.70% | -14.75% |
| 480 | | 7.97% | 1.05% | 0.94% | 0.89% | 0.42% | 0.18% | -2.29% | -4.55% | -2.90% | -8.44% |

Table 5 Error percentages between data means and modelled data. (red indicating >5% differential)

The modelled results are shown against the data means in Figure 5, this demonstrates the reliable scope of the model for prediction of lactation totals for TDY in the range [15,57]kg, Table 5 shows comparison with data means and Table 6 comparison to data medians

| L | T | 15 | 21 | 27 | 33 | 39 | 45 | 51 | 57 | 63 | 69 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 320 | Model results - data medians | 8.90% | 8.42% | 0.54% | -1.29% | -2.02% | -1.37% | -0.60% | 3.62% | 10.22% | 23.72% |
| 330 | | 8.82% | 3.88% | -0.11% | -1.16% | -2.39% | -1.05% | 0.19% | 2.34% | 2.85% | 6.57% |
| 340 | | 0.11% | 2.64% | -0.23% | -2.13% | -2.33% | -1.52% | -0.73% | 0.29% | 2.92% | 6.70% |
| 350 | | 0.15% | 2.42% | -0.63% | -1.68% | -2.48% | -1.33% | -0.63% | 1.02% | 4.73% | 14.62% |
| 360 | | 0.03% | 2.69% | 0.31% | -1.55% | -2.13% | -1.36% | -0.27% | 1.43% | 5.11% | 9.73% |
| 370 | | -0.04% | 1.73% | 0.39% | -0.89% | -2.14% | -1.88% | -0.42% | 0.41% | 5.26% | 14.81% |
| 380 | | -0.84% | 3.79% | 0.41% | -1.07% | -2.61% | -2.00% | 0.10% | 0.78% | 0.91% | 9.33% |
| 390 | | 1.56% | 2.56% | 0.66% | -1.50% | -2.86% | -1.83% | 0.00% | 1.97% | 4.74% | 5.39% |
| 400 | | 4.06% | 0.33% | -0.33% | -1.01% | -1.92% | -1.69% | -0.68% | 1.04% | 3.25% | 5.81% |
| 410 | | -2.63% | 3.31% | -0.50% | -1.15% | -1.97% | -1.63% | -0.61% | -0.53% | 3.97% | 8.19% |
| 420 | | -1.03% | 3.71% | 0.33% | -0.61% | -1.96% | -1.26% | -0.51% | 1.38% | 4.42% | 0.65% |
| 430 | | -6.04% | 2.03% | 0.10% | -1.51% | -1.63% | -0.95% | -0.47% | 2.37% | 1.30% | 6.04% |
| 440 | | 4.32% | 3.25% | -0.21% | -0.50% | -0.90% | -1.29% | 0.64% | 3.77% | 3.58% | 15.44% |
| 450 | | -0.98% | 4.42% | 1.41% | -1.40% | -1.26% | -0.76% | 1.00% | 2.53% | 0.21% | 7.81% |
| 460 | | 6.37% | 0.67% | 1.85% | 0.55% | -0.80% | 0.12% | 1.64% | 2.42% | -0.32% | 15.32% |
| 470 | | 1.00% | 4.93% | 2.00% | -0.02% | 0.04% | 0.05% | 0.04% | 2.46% | 11.04% | 8.32% |
| 480 | | -6.72% | 3.56% | 1.67% | 0.39% | 0.44% | 0.01% | 2.62% | 4.72% | 2.82% | 9.65% |

Table 6  Error percentage between data medians and modelled data red indicating >5%

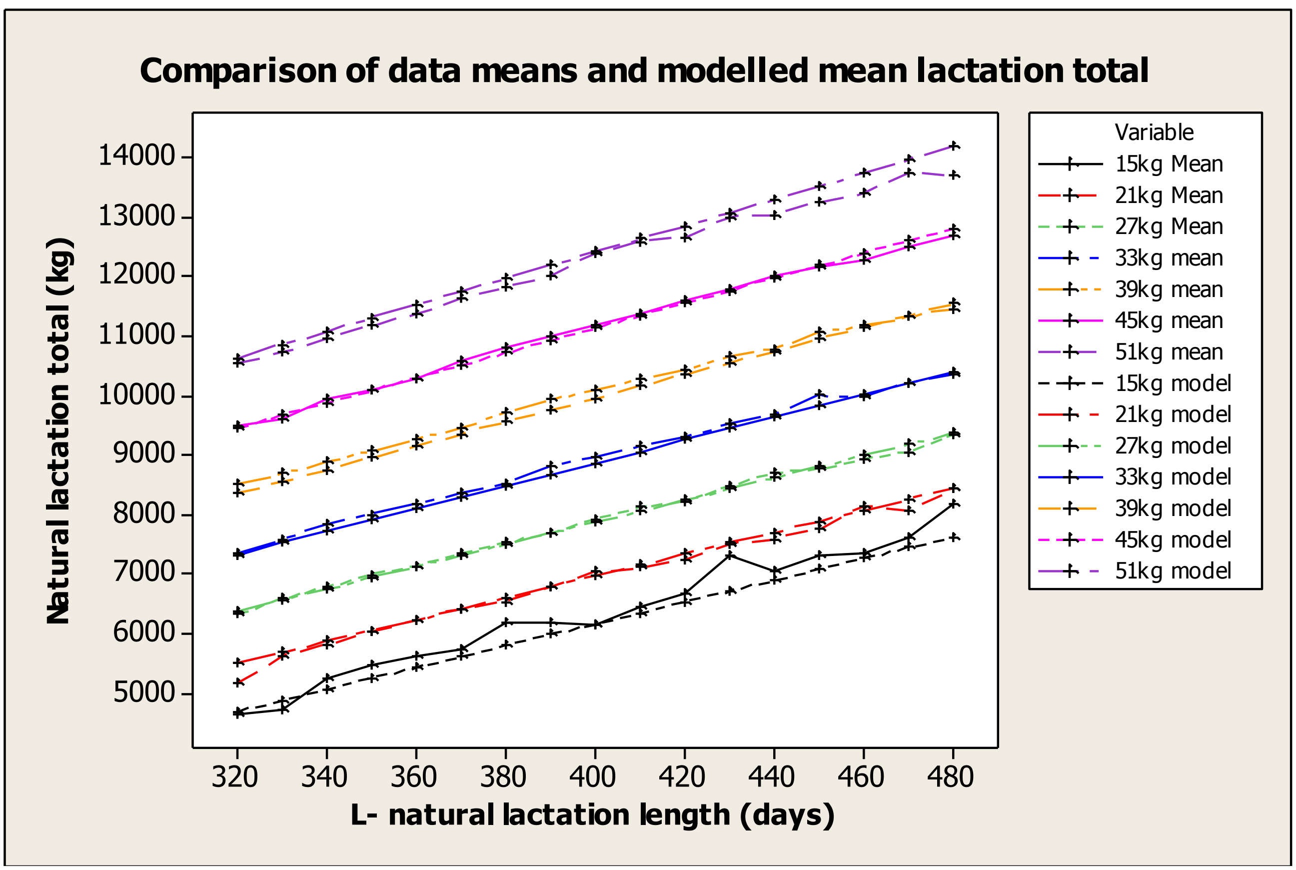



Figure 5 showing the relationship between the data means and the modelled output

### 2.4.6. The production model

A simple model for estimating total lactation production was derived which could be used to generate financial values for lactation total from TDY and ici. This model would fit the objectives of the project as mean daily output can be calculated for any lactation length and performance level. It can be used within the iterative model to calculate output for animals conceiving in any given iteration.

The mean average milk value income per day of ici model is shown below in Mathcad 2001i. The variables are as described in section table 1 and the functions δ, α and β as in 2.2.3

$$\frac{MP}{100 - RR}\left[\left[\sum_{n=0}^{\infty} \beta(RR,PR,n)\left[19.22 - 0.1074TDY + 0.003249\,TDY^2 + \frac{(130.9\,TDY - 3200)}{VWP + 285 + 10.5 + 21n}\right]\right]\right.$$

$$\left. + \delta(RR,PR,\alpha)\left[19.22 - 0.1074TDY + 0.003249\,TDY^2 + \frac{(130.9\,TDY - 3200)}{VWP + 285 + 10.5 + 21\alpha}\right]\right]$$

## 2.5 Feed costs sub model

### 2.5.1 Background

Nutrition costs represent the largest sector of variable costs in milk production. The Rural Business Survey 2011 (FBS, 2013) indicated that feed costs constituted between 57 and 60% of variable costs. This study is based specifically on the Holstein Friesian breed which precludes most low cost systems however both the modelling output and the data analysed will contain a mixture of both permanently housed and grazing systems. The grazing systems incur lower overall costs for animal nutrition, as a result it was decided that feed cost modelling could be based upon three production status within the intercalving period;

Early lactation feed cost linked to TDY for a fixed number of days including provision for a flat rate maintenance cost.

Later lactation feed cost linked to the mean daily production for the remainder of the productive lactation cost alongside a flat maintenance cost.

A flat rate cost for the dry period.

This reflects costs for the various levels of herd production and, applied within the iterative model, would reflect the variation associated with lactation length. A proportional summation would give a daily cost (£/day) for any permutation of management criteria used.

### 2.5.2 The feed cost model design and output

The method applied is analogous to that of Meadows et al (2005) with prevailing market costs to be used within the description as above. Given the same input yield the model would output the same early lactation costs for all cases reflecting common practice of early lactation animals being fed flat rate until a threshold point is reached

The later lactation costs reflect variation in the number of days included (by use of the iterative model ) and yield. Applying the cost by mean yield per day ici reflects the lower overall costs associated with lower yielding herds and uses a yield base relevant to later lactation animals.

Dry period costs vary across management types however, due to the combination of the dry period length and the low variation in daily cost, it was decided that a flat rate for this period would be adequate.

Feed cost per day

Taking the variables as described in 2.2.2, the model is applied in four components, total early lactation costs, mid lactation maintenance costs, mid lactation per kg costs and dry period costs. The sum of the four components is divided down by the mean ici function ($\Omega$ )

Early Lactation Costs

EMC(ELM + ELL*TDY)

Dry Period Costs

DP*DRY

Mid lactation costs

Mid lactation maintenance

$$\frac{MLM}{100-RR}\left[\left[\sum_{n=0}^{\alpha}\beta(RR,PR,n)(VWP-EMC-DRY+285+10.5+21n)\right]+\delta(RR,PR,\alpha)(VWP-EMC-DRY+285+10.5+21\alpha)\right]$$

Mid lactation production

$$\frac{1}{100-RR}\left[\left[\sum_{n=0}^{\alpha}\beta(RR,PR,n)\,MLL\left[19.22-0.1074TDY+0.003249TDY^2+\frac{(130.9TDY-3200)}{VWP+285+10.5+21n}\right](VWP-EMC-DP+285+10.5+21n)\right]+\right.$$

$$\left.\delta(RR,PR,\alpha)\,MLL\left[19.22-0.1074TDY+0.003249TDY^2+\frac{(130.9TDY-3200)}{VWP+285+10.5+21\alpha}\right](VWP-EMC-DP+285+10.5+21\alpha)\right]$$

### 2.6 AI and Service costs

#### 2.6.1 Background

AI and service costs equate to c 4-7% of variable costs depending upon herd reproductive performance and breeding strategy. In the wider context of the model this is relatively low but as reproductive performance is considered service costs require inclusion for completeness of variable costs.

PR (the product of conception and submission rate) gives the probability of a cow getting in calf in any given oestrus period or, in this model, each iteration. In respect of true costs we can observe that comparing two herds with the same PR, a herd with high conception and low submission rates will have lower breeding costs than one with high submission and low conception due to the total services required. Hence it could be considered that both variables should be included in the model however sensitivity analysis of fertility performance was not an objective of the research and so use of the single variable was considered adequate

It was considered that although voluntary culls will be unlikely to be served, many involuntary culls would be served the maximum number of times before they were considered infertile and so the average number of services would represent this sector of the herd within the cost structure.

#### 2.6.2 Breeding cost model

These costs are calculated directly from the iterative model. For any iteration the functions β and δ give the number of cows conceiving in that iteration, applying the definition of PR then the number of services required in each iteration is given by the total cows conceiving multiplied by 100/PR, as below.

$$h := \frac{AI}{\Omega(100 - RR)}\left[\left[\sum_{n=0}^{\alpha} \beta(RR,PR,n)\,(n+1)\right] + \delta(RR,PR,\alpha)\,(\alpha+2)\right]$$

### 2.7 The completed model

#### 2.7.1 Model construction

The final stage of the process was to collate these components and add suitable data entry and results retrieval points which was completed in Microsoft Excel 2007. The model was also written in Mathcad 2001i professional  (1986-2001 MathSoft Engineering & Education, Inc.) and this is shown below in its complete form for reference.

Variables in use

$RR := 25 \quad PR := 15 \quad TDY := 45 \quad VWP := 30 \quad AI := 25 \quad MP := 0.25$

$MLM := 1 \quad MLL := 0.05 \quad ELM := 1 \quad ELL := 0.08 \quad EMC := 120 \quad DRY := 1.2 \quad DP := 56$

$£HF := 300 \quad £HM := 45 \quad £BF := 136 \quad £BM := 182 \quad HV := 1750 \quad DR := 8 \quad CCV := 400$

$DEAD := 150$

The alpha fuction controls the number of iterations

$$\alpha := \mathrm{floor}\left[\frac{\ln\left[\frac{RR}{(200 - RR)}\right]}{\ln\left[1 - \left(\frac{PR}{100}\right)\right]}\right] - 1$$

The beta function is the iterative process delivering the proportion for each given iteration

$$\beta(RR, PR, n) := \left[100 - \left(\frac{RR}{2}\right)\right]\left(1 - \frac{PR}{100}\right)^{n} - \left[100 - \left(\frac{RR}{2}\right)\right]\left(1 - \frac{PR}{100}\right)^{n+1}$$

The delta function completes the iterative process by keeping the last iteration above the lower bound of 0.5RR

$$\delta(RR, PR, \alpha) := \left[100 - \left(\frac{RR}{2}\right)\right]\left(1 - \frac{PR}{100}\right)^{\alpha+1} - \frac{RR}{2}$$

The omega function calculates the mean intercalving interval

$$\Omega := \frac{1}{100 - RR}\left[\left[\sum_{n=0}^{\alpha} \beta(RR, PR, n)(VWP + 285 + 10.5 + 21n)\right] + \delta(RR, PR, \alpha)(VWP + 285 + 10.5 + 21\alpha)\right]$$

## Milk production daily model

$$a := \frac{MP}{100 - RR}\left[\left[\sum_{n=0}^{\alpha} \beta(RR,PR,n)\left[19.22 - 0.1074TDY + 0.003249TDY^2 + \frac{(130.9TDY - 3200)}{VWP + 285 + 10.5 + 21n}\right]\right]\right.$$
$$\left. + \delta(RR,PR,\alpha)\left[19.22 - 0.1074TDY + 0.003249TDY^2 + \frac{(130.9TDY - 3200)}{VWP + 285 + 10.5 + 21\alpha}\right]\right]$$

## Feed costs model

### early lactation cost

$$b := EMC(ELM + TDY\,ELL)$$

### Dry period costs

$$c := DP\,DRY$$

### Mid lactation maintenance

$$d := \frac{MLM}{100 - RR}\left[\left[\sum_{n=0}^{\alpha} \beta(RR,PR,n)(VWP - EMC - DRY + 285 + 10.5 + 21n)\right] + \delta(RR,PR,\alpha)(VWP - EMC - DRY + 285 + 10.5 + 21\alpha)\right]$$

### Mid lactation production

$$e := \frac{1}{100 - RR}\left[\left[\sum_{n=0}^{\alpha} \beta(RR,PR,n)\,MLL\left[19.22 - 0.1074TDY + 0.003249TDY^2 + \frac{(130.9TDY - 3200)}{VWP + 285 + 10.5 + 21n}\right](VWP - EMC - DP + 285 + 10.5 + 21n)\right]\right.$$
$$\left. + \delta(RR,PR,\alpha)\,MLL\left[19.22 - 0.1074TDY + 0.003249TDY^2 + \frac{(130.9TDY - 3200)}{VWP + 285 + 10.5 + 21\alpha}\right](VWP - EMC - DP + 285 + 10.5 + 21\alpha)\right]$$

$$feed := \frac{b + c + d + e}{\Omega}$$

### Cull and Replacement rate functions

$$f := \frac{(RR - DR)CCV - DR\,DEAD - RR\,HV}{100\Omega}$$

$$g := \frac{1.1RR(£HF + £HM) + (50 - 1.1RR)(£BF + £BM)}{100\Omega}$$

## Service cost model

$$h := \frac{AI}{\Omega(100 - RR)}\left[\left[\sum_{n=0}^{\alpha} \beta(RR,PR,n)\,(n+1)\right] + \delta(RR,PR,\alpha)\,(\alpha+2)\right]$$

## Model output

$$output := a - feed + f + g - h$$

### 2.8 Summary

Chapter 2 outlines the economic factors considered and the associated modelling required to output comparative data based upon the concept of a baseline cow representing the herd. Although the model will be run in Microsoft Excel (registered trademark of Microsoft) the model has also been written in matchcad (Mathsoft apps) allowing for future reuse or refinement. Although the semantics of programs change, the underling mathematical concepts could be easily retrieved and reapplied for any modelling package thus giving the work the level of repeatability that is required for future adaptation.

The bespoke milk production model is relatively simplistic however it's fundamental basis was to derive figures that were absolutely relevant to the period under analysis as opposed to using previously described models. It was notable that higher level animal evaluation systems are based upon best linear unbiased prediction priniciples (BLUP), these remove the inconsistencies of lactation and projected lactation total by taking into account all test day weighing results for individual animals. Although this would facilitate higher levels of accuracy the output would be based upon lactation length and total production which may be lead to difficulties in comparison at farm level. For this research a comparative measure of animal performance was required that could be easily related to by farmers, a test day weighing at a given point can easily be established at both individual and herd mean level allowing for such comparison to be made. The simplified model also draws upon some blup principles by considering the entire lactation for every animal in the analysis as opposed to a 305 day total as in some other work. It has to be recognised that there are shortfalls in all such analysis, milk records are susceptible to a range of inaccuracies from human error to badly recorded and identified animals, it also has to be considered that there may be a tendency in the UK for a certain demographic of farms to use such subscription services which may affect results in comparison to a true national figure.

The combination of bespoke production modelling with prevailing costs combined with the recorded algorithms gives a model with can be representative of any period of production, the lactation modelling could be easily replaced by any future enhanced model if required as could all variable values. It is considered that the model is fit for the purpose to be undertaken.

## 3 Results

### 3.1 Introduction

The completed model was used to evaluate permutations of management criteria relevant to UK Holstein breed and management based upon published performance (Hanks and Kossaibati, 2012) on 4 different management factors. In line with the research objectives four different lengths of VWP were reviewed and within each of these further analysis was undertaken for 8 TDY levels, 3 PR and 2 RR giving 192 different permutations for evaluation;

VWP 30, 40, 50, 60 days TDY 24, 28, 32, 36, 40, 44, 48, 52 kg

RR 25, 33 % PR 12.5, 17.5, 22.5 %

As described in Methods 2.2.2, the model contained many variables which were not considered within the sensitivity analysis outlined in table 7 below;

| Calf value | | | |
|---|---|---|---|
| RR | Replacement rate | **Var** | % |
| £HFF | Holstein heifer calf value | 300 | £ |
| £HFM | Holstein bull calf value | 5 | £ |
| £BF | Beef Heifer calf value | 148 | £ |
| £BM | Beef bull calf value | 197 | £ |

| Replacement cost | | | |
|---|---|---|---|
| RR | Replacement rate | **Var** | % |
| DR | On farm death rate | 8 | % |
| HV | Heifer purchase price | 1750 | £ |
| CCV | Cull cow value | 450 | £ |
| Dead | Dead removal cost | 150 | £ |

| Milk yield per day | | | |
|---|---|---|---|
| VWP | VWP | **Var** | Days |
| PR | Pregnancy rate | **Var** | % |
| TDY | Test day yield | **Var** | kg |
| MP | Milk price | **0.25** | £ |
| RR | Replacement rate | **Var** | % |

| Feed costs per day | | | |
|---|---|---|---|
| VWP | VWP | **Var** | Days |
| PR | Pregnancy rate | Var | % |
| TDY | Test day yield | **Var** | kg |
| ELM | Early lact maintenance | 1 | £ |
| ELL | Early lactation per litre | 0.09 | £ |
| MLM | Mid lact maintenance | 0.8 | £ |
| MLL | Mid lactation per litre | 0.07 | £ |
| DRY | Dry maintenance | 1.2 | £ |
| DP | Dry period length | 56 | days |
| EMC | Change early to mid | 120 | days pp |
| RR | Replacement rate | **Var** | % |

| Insemination costs | | | |
|---|---|---|---|
| RR | Replacement rate | **Var** | % |
| PR | Pregnancy rate | **Var** | % |
| AI | Insemination cost per service | 25 | £ |

| **Key** | |
|---|---|
| **var** | Evaluation Variable |

Table 7 Values applied for evaluation parameters

The results were stored in Microsoft Excel and then the tabular output was exported to Minitab 16 for subsequent analysis.

## 3.2 Presentation of results

### 3.2.1 Introduction

This section presents the results and comparative analysis based upon VWP, PR and RR. Although TDY was used as a parameter in the analysis, the focus of the evaluation is upon the effects of the former three traits at specific yield levels as opposed to a review of performance by yield. The full table of evaluation results are shown in Appendix 5.1, table A4 however interpretation is difficult in this format hence this results section uses graphs and data tables to improve interpretation.

### 3.2.2 Voluntary waiting period analysis

In line with the main objective, the first analysis is based upon VWP. Figure 6 shows the relative effects of varying lengths of VWP against the other parameters, this is then expanded to give a direct comparison of the economic effects of varying VWP length within the framework of herd production level.

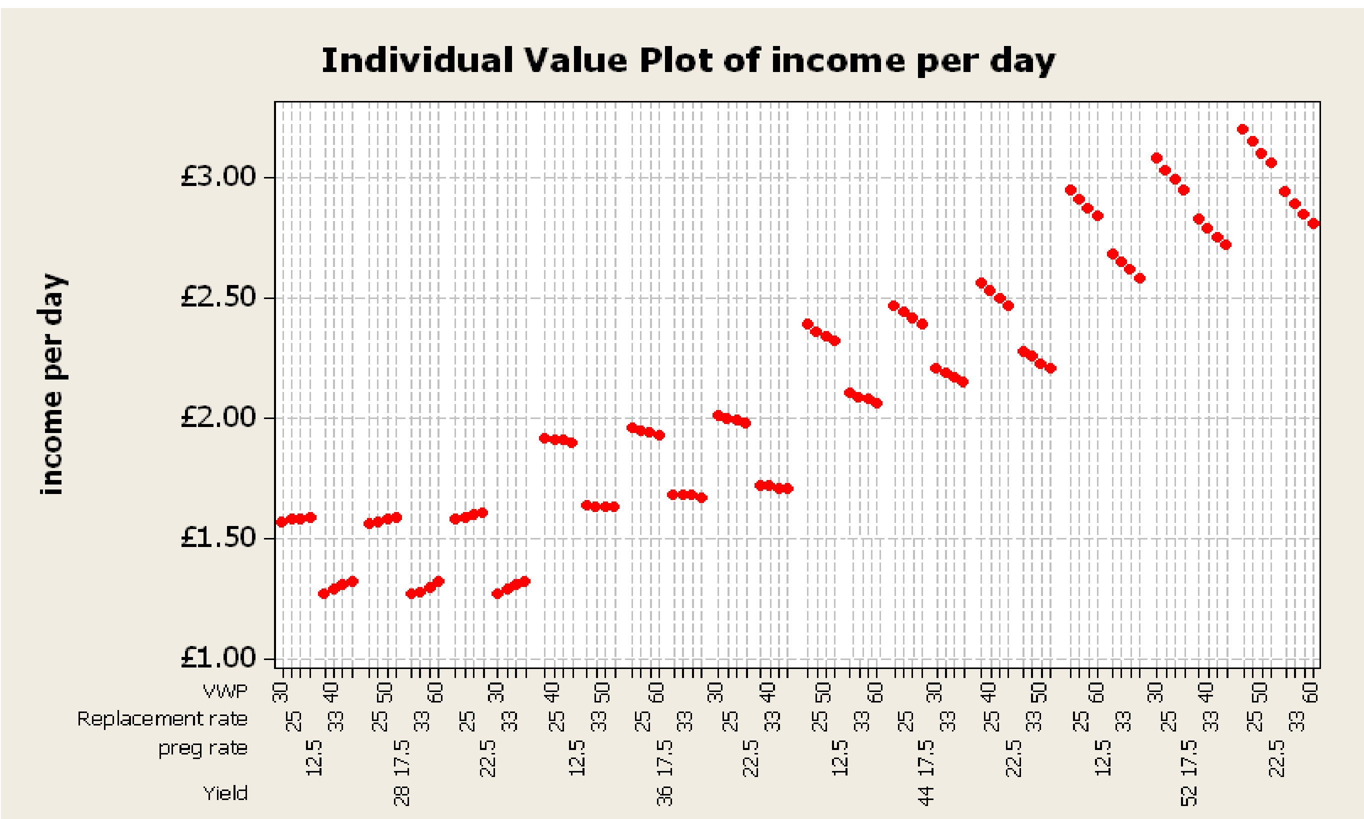



Figure 6 Individual value plot for 4 levels of production performance across the 3 comparators

The data points are in 4 sets of 6 clusters, each of the set of 6 clusters represents a level of production. Within each yield level the clusters represent groups with the same PR and RR but with each point in the cluster representing a different length of VWP. The yield levels are divided laterally into 3 pairs of clusters, each pair representing a different PR. Each yield group also divides into 2 sets of three clusters in the x plane with each set representing the different RR

Figure 6 gives a visual interpretation of the main results for the VWP analysis. To simplify output not all evaluated yield levels are shown however the developing relationships with increasing yield are consistent across all yield evaluation levels.

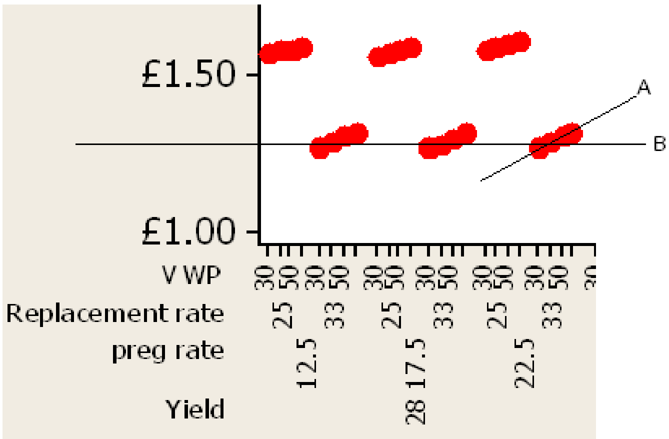



Figure 7 The 28kg production analysis

For low yielding herds the results suggest that short VWP are financially disadvantageous with a trend towards increased income per day with later commencement of breeding ( A, figure 7). The single dominant factor affecting income is RR with clear differences between the 25% and 33% cluster groups (each consecutive grouped cluster representing one RR analysed). Within the 28kg yield herds there appears to be little disadvantage in lower PR as the clusters, when compared for that parameter, take almost the same value for all three levels analysed (B, figure 7). These results are closely related to the yield modelling, further analysis of the milk per day function ;

$M\ ici = 19.22-0.1074TDY+0.003249TDY^2 + (130.9TDY - 3200)/L$

shows a stationary point for mean milk per day for all evaluated CI at a level of 18.9 kg per day associated with a TDY of 25.35kg. With the financial factors included it would appear that 32 kg TDY is the approximate point at which a reduction in VWP begins to show positive financial benefits. The range of income per day across all measured parameters was 34p per day

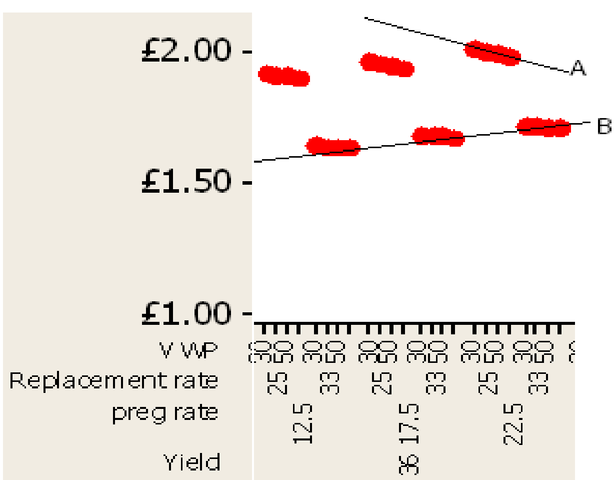



Figure 8 The 36kg production analysis

Taking the second set of 6 clusters (Figure 8) it can be seen that as vwp is increased there is a decrease in income per day although of small magnitude with a maximum difference of 3p per day between VWP's of 30 and 60 days for herds at this level (A, Figure 8). RR is the dominant factor affecting income(range 29p) in these herds but it can also be observed that, for each RR level, the trend for income is positive with increasing PR (B, Figure 8) in line with perceived expectations (range 3p). The range of income per day across all measured parameters was 38p per day.

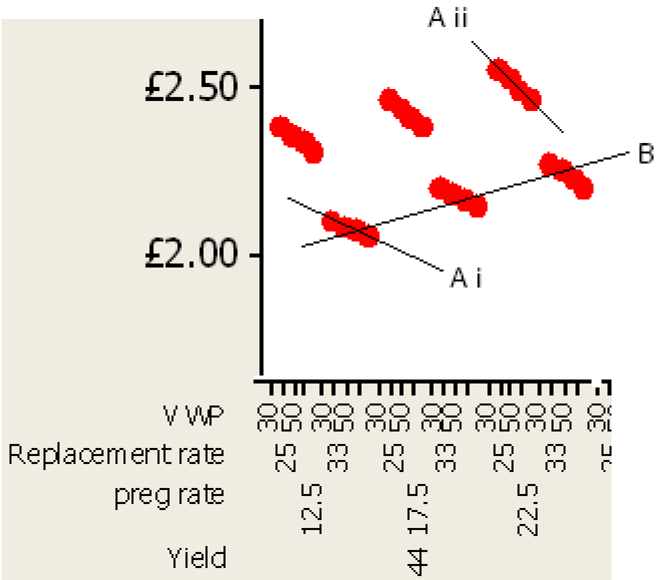



Figure 9 The 44kg production analysis

The third set of clustered results on the graph represent the herds with 44kg TDY. Once again RR is the single biggest financial factor in the analysis, however, compared to the previous two yield levels, the herds with higher RR but good fertility and short vwp are closer in respect of income per day to those with lower RR but where breeding is commenced later and is ineffective (4p per day). For these herds the advantages of short vwp are apparent (Figure 9 Ai and Aii) the angle of the cluster groups would indicate that the advantage of short vwp is greater in herds with good fertility and low RR (max range 8p). For these herds, PR is more important with a range of 18p per day difference between the best and worst performance (indicated by B, Figure 9). The range of income per day across all measured parameters was 50p per day.

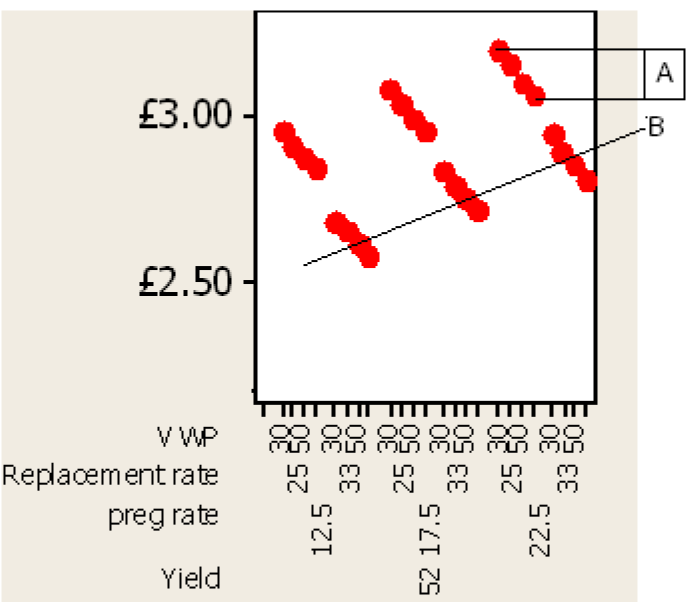



Figure 10 The 52kg production analysis

The final group shown in this analysis are the herds with an average TDY of 52kg at day 50-60pp. For this group we can observe the growing importance of reproductive performance and early commencement of breeding in optimising daily income. RR continues to have the greatest overall impact at 27p maximum differential between 25% and 33% RR in herds with 12.5% PR and 30 day VWP. At this yield level the best performing herds for both short VWP and 22.5% PR have higher income per day than many of the groups analysed with lower RR but poorer reproductive performance. PR influenced income per day by similar levels up to a maximum of 26p for herds where VWP is 30 days and RR is 25% (B, Figure 10). At this level the length of VWP also has significant impact on income with a maximum differential of 14p per cow per day for herds with 25% RR and 22.5% PR (A, Figure 10). The range between the best and lowest income per day for the 52kg analysis group was 62p to a maximum of £3.20.

The final comparison for the VWP analysis shows the changing relationship between all three parameters with changing herd performance levels. As above, the evaluation parameter is herd average

TDY between days 50 and 60pp, for consistency the same yield level groups are indicated (Figure 11). The pie charts show that, at a point close to a 48kg TDY performance, the relationship between RR and the combined values of VWP and PR are about the same indicating the increasing importance of reproductive efficiency with higher performance.

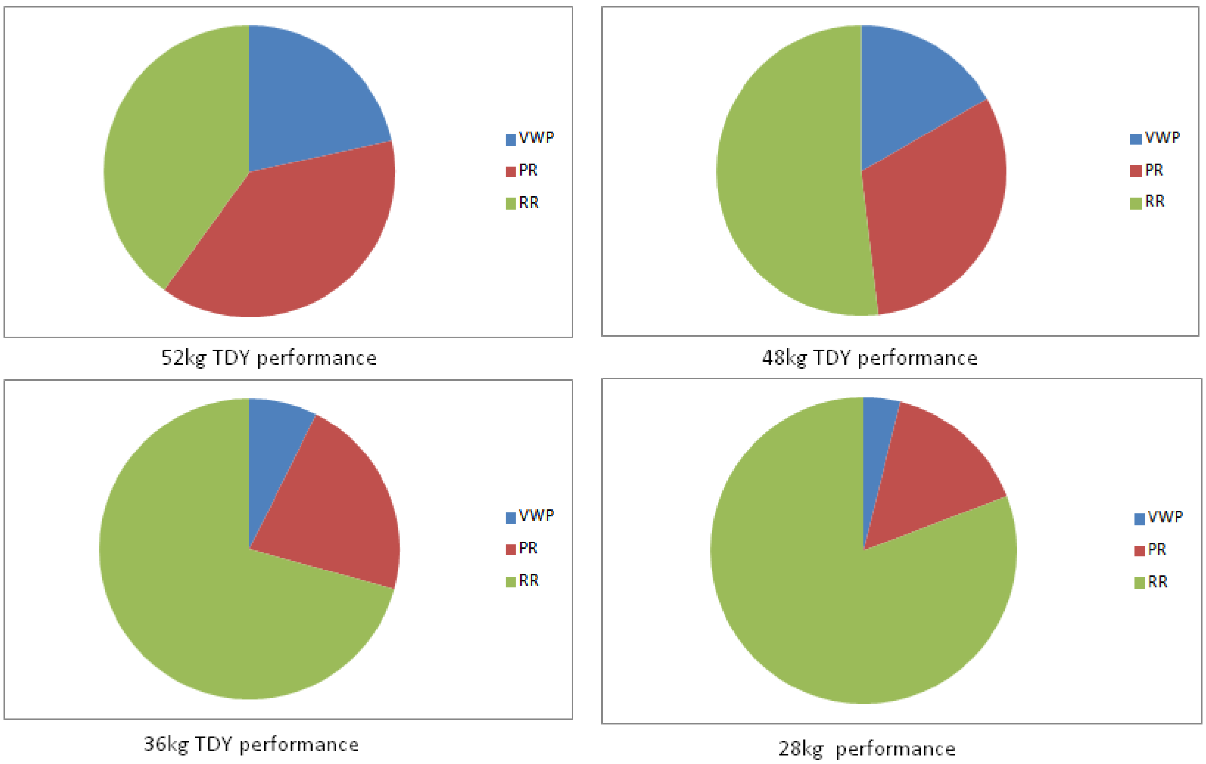



Figure 11 The changing relationship between the comparison parameters over 4 evaluation levels

In summary, the length of the VWP was the least dominant factor affecting income per day in this initial analysis. This section highlights the changing dynamic between yield level and the economics of breeding commencement although it could be considered that the majority of Holstein herds in the UK have average yields which would favour earlier commencement of breeding. The greatest financial advantage of short VWP is exhibited by the highest yielding herds which is the sector where the reproduction production antagonism has the greatest impact (Friggens et al, 2010). This provides insight into why increasing yields on some units have not necessarily increased income- the reason being that increasing production levels impact upon fertility and RR which negate the expected additional income generated by perceived increased milk sales. Table 8 gives an example of why combining yield with reproductive efficiency and longevity are fundamental to business performance;

| Yield (kg) | Pregnancy rate (%) | VWP (days) | Replacement rate (%) | ICI (days) | Mean milk per day | Milk income | Milk income per day |
|---|---|---|---|---|---|---|---|
| 52 | 12.5 | 60 | 33 | 440 | 30.7kg | £3380 | £7.68 |
| 48 | 12.5 | 60 | 25 | 452 | 29.2kg | £3215 | £7.11 |
| 44 | 22.5 | 30 | 25 | 371 | 23.4kg | £2577 | £6.95 |

| Yield (kg) | P R (%) | VWP (days) | Replacement rate (%) | Replacement cost | Service cost | Feed cost | Calf Income (£) |
|---|---|---|---|---|---|---|---|
| 52 | 12.5 | 60 | 33 | £489.50 | £109.50 | £1795.01 | £147.49 |
| 48 | 12.5 | 60 | 25 | £381.50 | £114.75 | £1709.76 | £153.18 |
| 44 | 22.5 | 30 | 25 | £381.50 | £84.50 | £1314.25 | £153.18 |

| Yield (kg) | P R (%) | VWP (days) | Replacement rate (%) | Replacement cost per day | Service cost per day | Feed cost per day | Calf income per day | **Income per day (£)** |
|---|---|---|---|---|---|---|---|---|
| 52 | 12.5 | 60 | 33 | £1.11 | £0.25 | £4.08 | £0.34 | **£2.58** |
| 48 | 12.5 | 60 | 25 | £0.84 | £0.25 | £3.78 | £0.34 | **£2.57** |
| 44 | 22.5 | 30 | 25 | £1.03 | £0.23 | £3.54 | £0.41 | **£2.56** |

Table 8 Similar financial performance across a range of management parameters

The example shown in table 8 indicates that similar levels of financial performance can be produced with an 8kg range in TDY at days 50-60pp, the differential in income per day between 52kg and 44kg performance is ~2p per cow per day. The causal factors of this similarity in economic performance levels are lower RR, improved reproductive performance and shorter VWP as indicated in the table. The nuances of these interrelationships between economic factors are difficult to establish within standard herd costing systems but analysis of the mean daily figures in the example cited give insight. Mean lactation income generated for the 52kg herd was £7.68 per cow per day whilst the 44kg herd generates £6.95. However comparison of the other evaluated factors shows that although the 52kg herd produced £803 per cow higher milk income in the lactation, the total production would be spread over 440 days as opposed to 371 days in the 44kg herd. The reduced CI in the 44kg herd combined with lower production feed requirements leads to a reduction of total feed costs by £0.54 per day against the 52kg herd. Replacement cost differential between the 52kg and the 44kg herds was 8p. The reproductive performance levels for the 44kg herd gave lower service costs (£25 per lactation lower per animal) but this only equated to 2p per cow per day against the other group as a result of reduced CI and cost dilution. Calf income differential per day was of low order with a differential of 7p per day in favour of the 44kg group due to the shorter CI . Overall the total income differential of 2p per cow per day between the comparative herds results in a total annual income differential of £7.30 less per cow for the 44kg herd.

In summary, maximising yields may not be economically optimal for all herds especially those where nutrition and herd management are such that performance levels in other key areas are compromised as a result. The results do indicate that where reproductive performance can be maintained, short VWP are financially advantageous with greatest effect in higher yielding animals. The analysis shows that for all herds with a TDY average in excess of 32kg, financial performance is enhanced by earlier rebreeding. Where all other evaluated parameters were managed at the most efficient level (PR of 22.5% and RR of 25%), a 30 day difference in VWP equates to 14p differential in income per cow per day or £51 per cow per year for herds with a 52kg average at a 50-60 day test day weighing.

### 3.2.3 Comparative analysis of other parameters

The analysis of the economic effects of VWP length established that, at low levels of production, short VWP may have a negative effect on income. It was also observed that as the production level of a herd increases, the effect on income of shorter VWP becomes positive and increasing in magnitude as yield level increases. However within the parameters evaluated length of VWP was the least significant, this section shows the results of a comparative analysis of the other two main variables . To evaluate the relative importance of these parameters, analysis was undertaken on the same four yield levels as in Figure 11. VWP was fixed at 30 days for consistency and contour charts were used to evaluate the dynamics of the two parameters across different performance levels.

Figure 12 illustrates the changing importance of RR and PR with production level. It can be observed that at the lower level of production (28kg) there is no effect on income across the variation in PR, for these herds RR is the single predominant factor in determining financial output.

The 36kg analysis shows that improved fertility levels enhance income. Evaluating the slope of the contour line at £2 income per day shows that a 10% variation in pregnancy levels analysed equated to 2% variation in RR .

The 44kg analysis shows the increasing significance of PR as herd production levels increase as indicated by the contour lines becoming less steep in comparison to the 36kg graph. This chart includes three tiers of daily income performance level ranging from £2 to £2.60 per day. The slope of the £2.40 contour is approximately 2.1 indicating that the financial differential for a ~2% change in PR would be equivalent to a 1% change in RR.

For the highest production tier analysed the significance of PR increases further, the slope of the £3.00 contour being ~1.5. For these herds optimisation of reproductive performance and enhancement of longevity has significant financial rewards, the results range on the analysis being 62p/cow/day. The diagonal contours indicate that average income can be achieved by achieving good performance in either parameter.

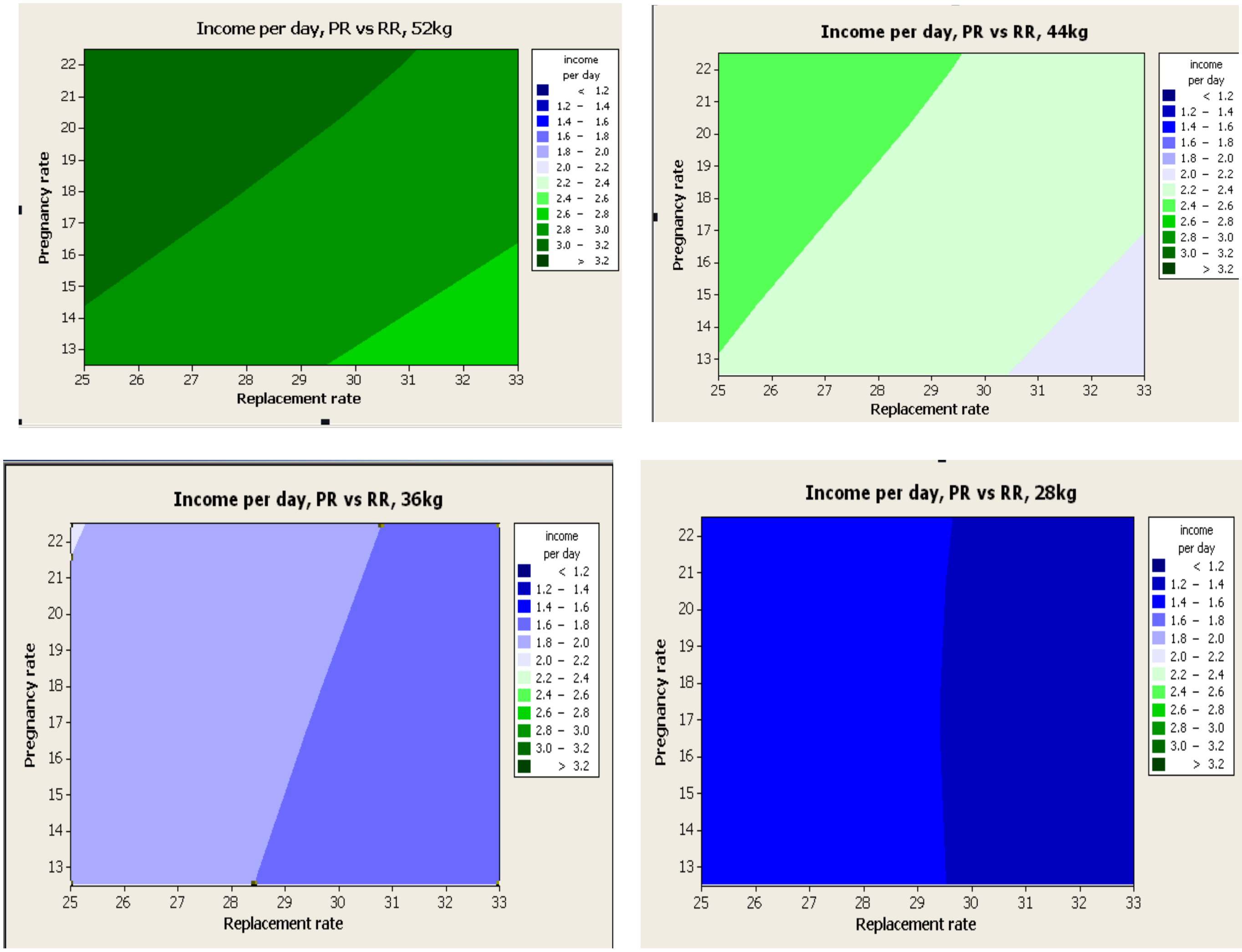



Figure 12 Evaluation of the effects of PR and RR across different production levels

### 3.2.4 Summary

The analysis of VWP length shows that the economics are directly related to yield and, for most UK herds, the earlier breeding is commenced the greater the financial advantage. The growing importance of PR with increasing TDY performance throughout the analysis is driven by improved yields per day of ici achieved in shorter lactations, conversely the flat mean yield per day indicated in the original yield analysis for lower yielding herds makes early service and conception financially disadvantageous. For all yield levels the economic importance of longevity is high, although the relative importance weakens with increasing yield due to the increasing economic value of the other parameters.

# 4 Discussion

## 4.1 Model design critique

### 4.1.1 Background data

The model was designed with the specific objective of taking current UK Holstein dairy production metrics and cost parameters and applying these to investigate economic impact across multiple herd management factors. Inchaisri et al (2011) suggested that use of actual data to derive an optimal VWP from existing records would be difficult however the use of bespoke modelling to reflect current production may overcome some of the weaknesses of existing models.

The most significant weakness of the analysis data was that it could not be randomised, analogous to a problem outlined upon use of US data (Lucy, 2001). Although the data set contained a full years results from a national MRO this does not preclude a risk that a certain demographic of UK dairy farms are more likely to use these services which would bias the results. Establishing whether such bias exists would be difficult as national figures quoted are usually derived from MROs and would carry similar weaknesses. This problem is not unique to this work though as the distributions and ranges used to construct other existing models generally have some exposure to secondary data.

Secondary data suffers more widely recognised problems of badly recorded calving and service information, distortions of volume production and unknown reasons for lactation end all of which affect the quality of results extracted (Albarrán-Portillo and Pollott, 2013). Arbel et al (2001) suggested that analysis of extended lactation may be analysis of a subgroup with increased probability of having suffered some form of lactation lengthening problem . In the wider context, secondary data does provide a large set upon which restrictions can be applied to mitigate many of the weaknesses. Arbel et al’s 2001 work demonstrated that primary research may suffer significant alternative problems, the main advantage of secondary data is that very large data sets should be more representative of a population and volume should dilute the effects of the problems outlined.

### 4.1.2 Review of the production model

The production models derived from the data were

$$\text{Lactation total (kg)} = (19.22-0.1074TDY+0.003249TDY^2)\,ici + 130.9TDY - 3200$$

$$\text{Mean milk per day of ici} = 19.22-0.1074TDY+0.003249TDY^2 + (130.9TDY - 3200)/ici$$

The project objective was to analyse the economic consequences of varying levels of VWP hence accurate modelling of production across the evaluation levels was of fundamental importance. It was considered that existing yield evaluation models may not be optimal for this purpose, the models of Wood (1967) and Van Arendonk (1985) were considered unsuitable as, with fixed coefficient values, these would not simulate variation within the yield modelling for differing amounts of days open. No precedents were found where the coefficients for these models were changed to functions of days open and it was considered that the complexity and validation of such an approach was prohibitive.

305 day lactation total was not considered suitable as the production comparator, previous work has indicated confounding effects of days open and increasing 305 day yields (Loeffler et al, 1999, Lee et al, 1997). The chosen method was analogous to the use of a TDY taken at day 90 (Albarrán-Portillo and Pollott, 2013) but differed by applying results from days 50 – 60 pp. It was considered that this would give a compromise between the increasing accuracy of production forecasting given by later lactation weighings (Danell, 1982) whilst minimising the effects of gestation upon yield (Olori et al, 1997).

The trends in the natural lactation totals derived from the national database were most accurately represented by a linear function when expressed with the independent variable ici and the dependent variable lactation total analysed upon distinct TDY level cohorts. The resultant model design comprised 2 variables, TDY recorded between days 50 and 60pp and ici. It accurately reflected the evaluation data as indicated in tables 5 and 6 within the required scope of the analysis.

This bespoke model reflected the research data set but, in comparison to other production models, may be considered over simplified through the exclusion of both season of calving and parity. The restrictions upon the analysis set were to include only multiparous animals of lactation 5 or lower, although there will be variation in production levels across these lactations, in respect of analysis the most significant aspect would be persistency. Exclusion of primiparous animals reduced persistency effects in the model as they exhibit higher persistency (Inchaisri et al, 2011; Arbel et al, 2001). Reviewing seasonality, the analysis was not designed to reflect the seasonal variations on feed and reproductive performance hence the lactation model fitted the homogenous nature of the overall analysis, the objective was to review the economic trends associated with early commencement of breeding as opposed to an analysis of performance by month. In common with other yield evaluation models, given a suitable reference data set it may be possible to adjust the coefficient values to simulate production for different applications although this was not investigated further.

Use of a national database to generate milk production modelling gives a generic picture of production. It may be considered that stratification by herd means would improve analysis for the effects of relatively high yielding animals (Dobson et al, 2007; Loeffler et al, 1999), however comparison of mean herd production is difficult as that also is measured upon 305 day lactation totals. Natural lactation performance would be worthless due to the direct effects of CI . As a result the generic model was considered acceptable within the context of the current project.

### 4.1.3 Review of the wider model

The production model made no allowance for any potential effects of early conception upon production in the subsequent lactation, although subsequent lactation yield may be affected by the length of the previous CI (Arbel et al, 2001) little other substantiated work was found. Evidence was found indicating that earlier service may result in lower CR, Ferguson and Skidmore (2009) indicated that submission rates are consistent throughout the lactation but that CR are lower leading to reduced PR which is in agreement with the Loeffler et al (1999) observation that service before day 80 was less likely to be successful. Inchaisri et al (2011) indicated that a reduction from a 7 week to a 6 week VWP would improve CI by 2 days whilst Ouweltjes et al (1996) found that herds commencing serving earlier recorded higher numbers of services per conception. The project model applied flat levels of PR irrespective of length of VWP which may appear to be a potential weakness however the modelling was designed to analyse herd performance through a generic model cow and, as such, was based upon the herd mean pregnancy rate, simulation of service success was neither an objective or a requirement.

An analogous argument to that of earlier service CR is whether there should have been consideration of lower CR in higher yielding animals. Inchaisri et al (2011) suggested that the probability of conception would be dependent upon 305 day yields, much evidence suggests that later conception leads to higher 305 day yields which is a cause and effect discussion (Olori et al, 1997, Lee et al, 1997). Ouweltjes et al (1996) indicated that higher yielding herds use more services per conception, this is concurrent with all research on the reproduction production antagonism. In respect of this model, the pregnancy rates applied are not linked to either yield or VWP and are entered at a level selected upon input hence the results are indicative of the performance levels chosen unlike those models which simulate herd production dynamics (Inchaisri et al, 2010 and 2011; Sørensen and Østergaard, 2003; Stott et al, 1999) where clearly such considerations are fundamental. As a result this area was not considered a weakness of the model and had no effect upon output.

Reviewing the strengths of the model the primary focus has to be the production modelling. As shown in Figure 5 the production model fitted the results from the data set analysis well, with production simulation being vital to any economic evaluation this gave the model a strong base upon which the additional parameters could be applied.

The main results were based upon a financial output, hence the results would suffer the same problems of losing relevance as outlined in section 1.4.1 with changing cost. The use of heat maps and graphing to compare relationships between economic factors mitigates this by abstracting the results from the financial framework, it is likely that the dynamics of these relationships would remain consistent in future although applied RR and PR levels may lose relevance as performance levels change.

The model used two techniques analogous to those used by Meadows et al (2005). The first is the pro rata application of income and costs allocated using the length of the interval between calving and culling in the final lactation. Clearly where mean lactations are used as a measure of lifetime this could lead to a scenario where the mean final lactation may be very short, for instance a RR of 31% would give an average lifetime of 3.2 lactations so a final lactation equivalent of 0.2 lactation between calving and culling. A final lactation of this length is considered unlikely and is a result of averaging however the application of pro rata results on this figure mitigates any effects this may have on overall economics. Secondly the method where all calves are removed from the herd at relevant values and then replacement requirements applied at market values allowed for relevant financial outcomes to be spread over the respective CI reflecting herd situations where there may be either excess stock to sell or insufficient replacements.

Although the application of purchasing replacements was considered a strength, it was noted that there may be a shortfall in respect of the values applied for this part of the analysis. This area of weakness was considered significant and, as such, required further analysis prior to discussion of the results.

#### 4.1.4 Replacement cost modelling

Analysis of the income per day divided by mean production per day of ici produces a figure comparable to mean margin per litre. Figure 13 shows a graph of the output for this analysis, PR and VWP were fixed giving an analysis of margin per kg against production level, shown for both replacement rate levels.

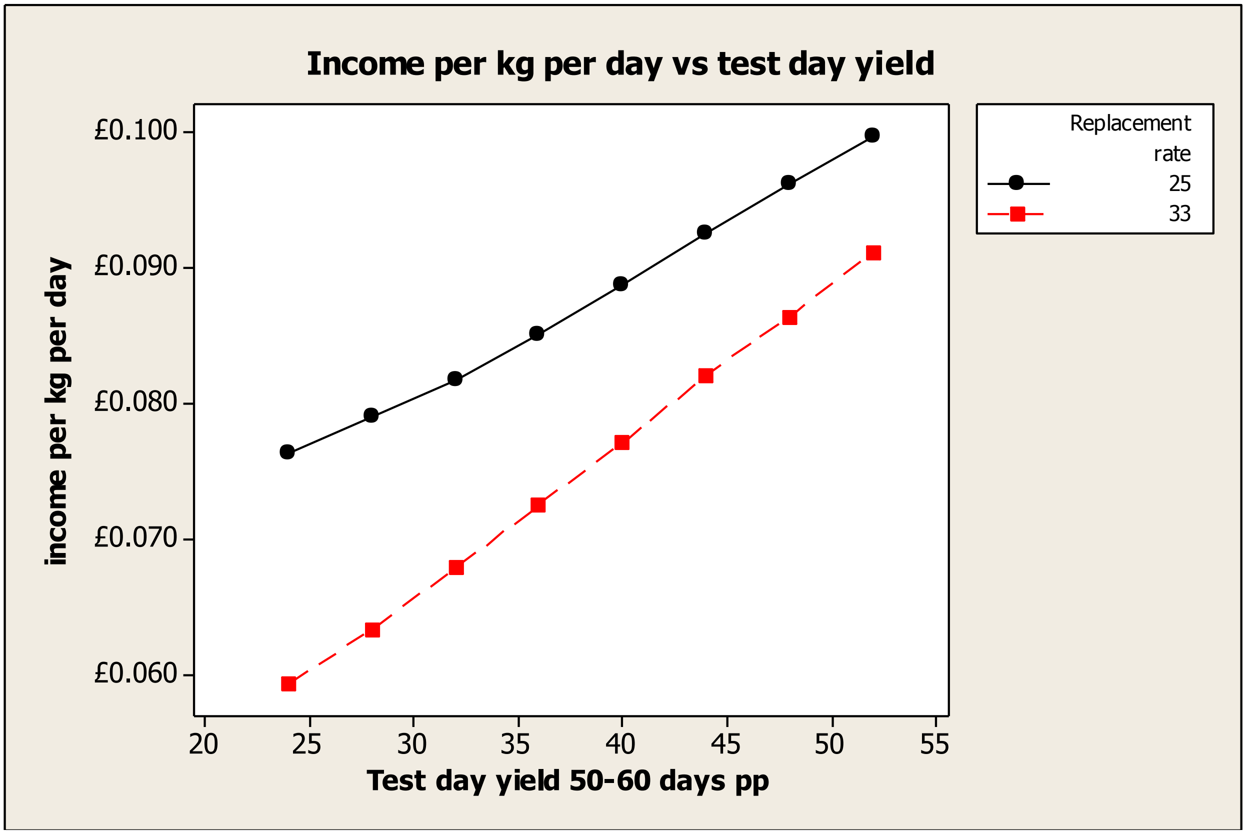



Figure 13 Margin per kg comparison against production level

We can observe that modelled margin per kg increases with increasing performance level. The authors experience would suggest that these trends are not correct and this is confirmed from 2011-2 statistics (FBS, 2013) which confirmed that, across similar factors to the model evaluation, herds with a mean yield of 7-8000kg delivered a margin £0.16 per kg whilst those with a of 6-7000kg yield delivered £0.18 per kg. The reason for this incorrect trend within the model is the division of flat rate replacement costs over total production. It is a challenge faced by lower output herds that fixed costs have to be borne over less output- where fixed costs remain static one of the attractions of increasing yield per cow is the dilution effect on fixed costs. The problem with the model is that the initial cost of the incoming heifers was set at a constant level, as a result an animal with the potential to produce 10500 kg had the same initial cost applied as one with 7000kg potential, this is not reflective of the market place. Hence modifying the model replacement costs by applying them as a function of production would proportionally reduce the cost levels applied. It is suggested that modelling heifer value on TDY potential may improve the model, a structure such as £710 + £20/kg TDY would give values representative of the market at the prevailing time.

The effects of this update to the model can be seen in figure 11.2b. We can observe that the margins are considerably closer across all yield levels evaluated with a wider differential on the higher replacement rates. Most notable is that the lowest yielding evaluation group does not result in the lowest margin. Overall the effect of the change is improvement to the model in respect of representing cost trends in production.

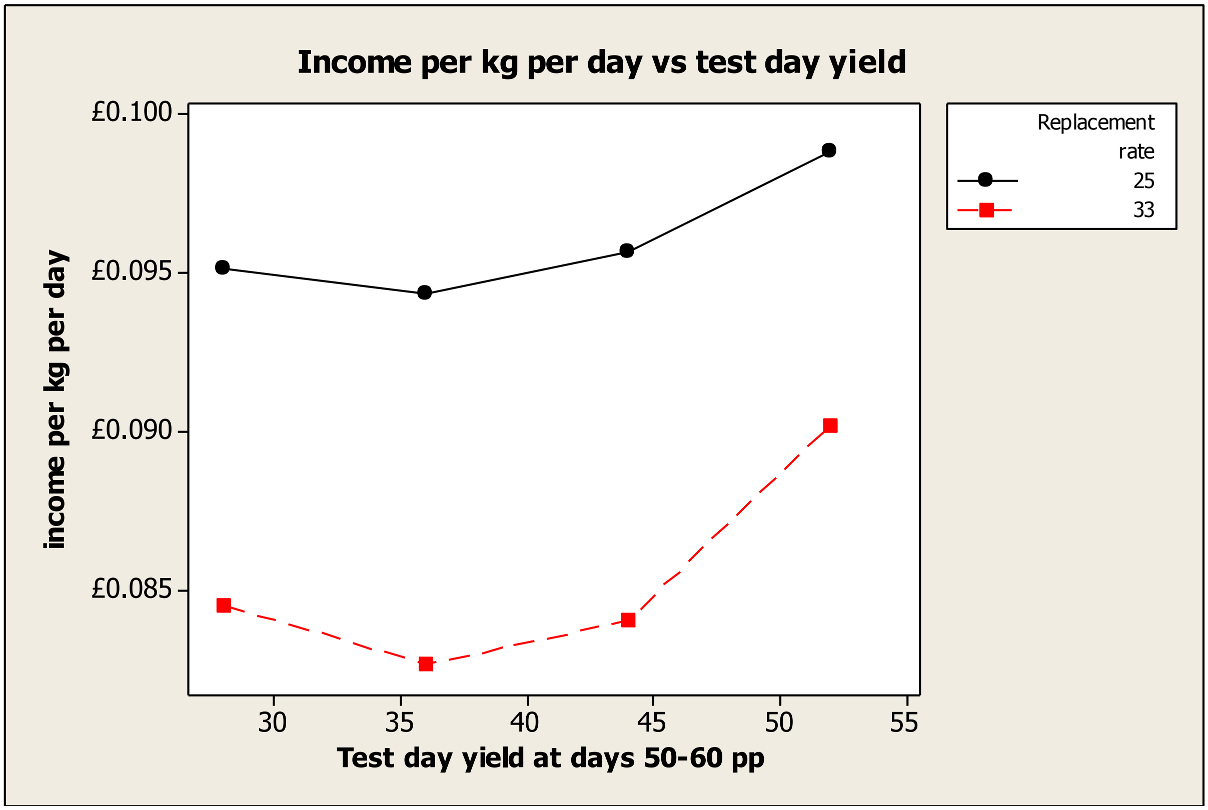
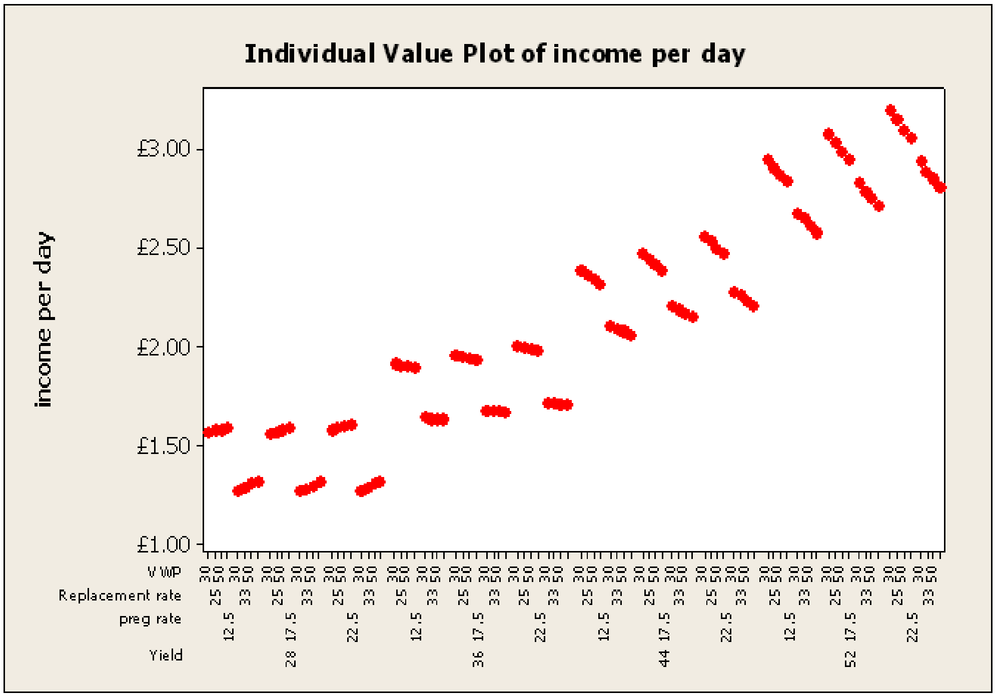


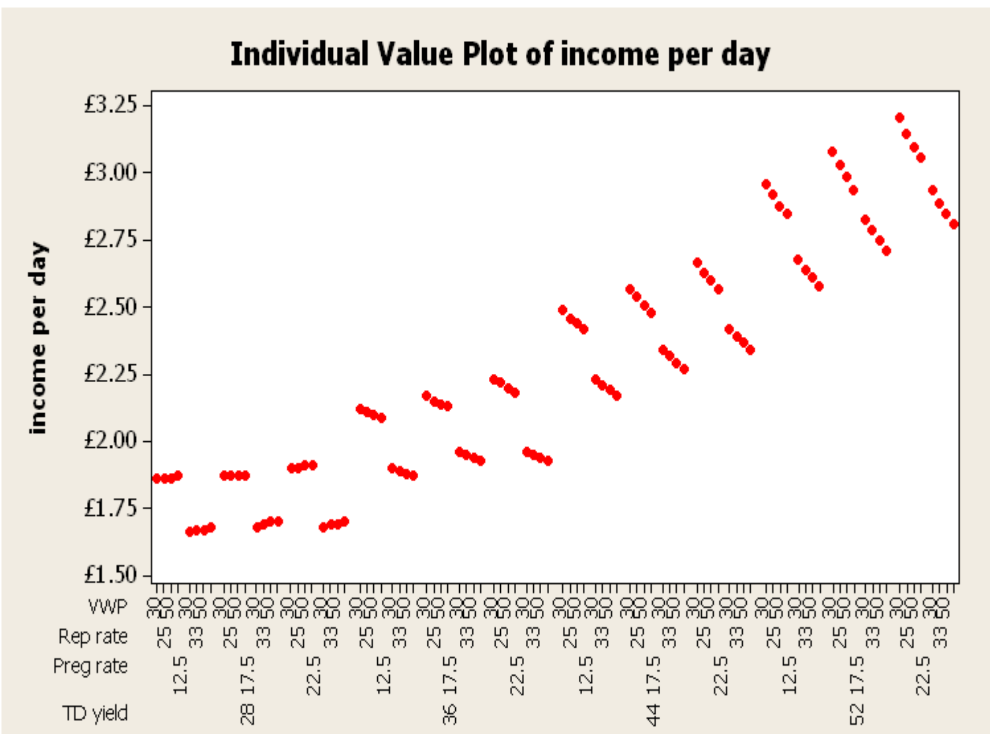

Figure 14  Revised margin per kg comparison against production level

In respect of the wider discussion to follow, it is important to analyse the effects of these changes on the wider analysis thereby assessing  the validity of the main results. It was decided to recreate the same chart as shown figure 6 but with the alternative replacement cost model applied. To simplify the comparison both the original figure and the updated chart are shown together in figure 15.

In more detail we can observe increased income per day for all bar the highest yielding evaluation group. Although the cluster arrangement gives the impression of greater differentials this is a result of rescaling as opposed to a change to the dynamics of the main results. In conclusion all comparative trends given within the results section remain consistent, this is important for the discussion as the relationships shown between the parameters evaluated remain valid.




The original results as per figure 6




The results after revised modelling of replacement costs applied

Figure 15 Comparison of model output after changes made to replacement cost

## 4.2 Discussion of results

### 4.2.1 Voluntary waiting period analysis

The model indicates that for high yielding animals shorter VWPs and, by association, reduced days open are financially advantageous but with reducing economic impact as yield level decreases. This is in agreement with Inchaisri et al (2011) who observed that a decrease in yield potential would increase the probability of longer VWPs being optimal. The results obtained in this project indicated that the lowest yielding groups showed an increase in income per day corresponding to increasing VWP however the magnitude was very low and not of economic significance. Although lower yielding animals may appear to contribute higher returns to the herd by being bred later any decision would need to be qualified upon the basis of why the animal is low yielding; if it is a result of some form of yield impact event then early resumption of breeding would return the animal to the herd in a higher production state earlier however for animals with naturally low levels of production the results would justify a decision not to commence breeding early particularly where that may reduce fertility intervention and associated costs . Decisions of this type are analogous to those highlighted by Ouweltjes et al (1996) where breeding decisions may be based upon the individual production relative to the herd mean, in that case the evidence indicated that higher yielding animals were bred later. The results of this project would indicate that decisions to breed low yielders earlier and high yielders later are the converse to logical deductions from economic analysis however these management decisions may be justifiable at farm level. If we apply these results in address to the question of optimal rebreeding stage for individual animals, we find that by taking fixed herd parameters for pregnancy rate at 17.5% and a replacement rate of 33%, a 52kg TDY animal with a 60 day minimum VWP delivers £3.50 per day of ici while a 48kg TDY animal with a 30 day VWP generates £3.22. These results indicate that although rebreeding later in higher yielders may not be optimal these animals will continue to provide higher income than lower yielding counterparts bred earlier, this observation is in agreement with discussions on later rebreeding outlined by Lee et al (1997). The overall suggestion is that the decision on rebreeding commencement may be based upon factors including replacement availability, locally observed success rates for early service or cost reduction by reducing fertility intervention costs as opposed to optimisation of milk output. An outcome of this would be that individual herds may have contributory factors which mean that a theoretically optimal commencement of breeding either may not be or not be perceived to be optimal for that specific business.

As shown by these results, short VWPs or reduced days open in higher yielding animals are financially advantageous. This is in agreement with much previous literature including Stott et al (1999); Meadows et al, 2005; Sørensen and Østergaard (2003) and Inchaisri et al, (2011) who all indicated similar relationships. The first objective of the project was to establish whether this paradigm remained valid against the backdrop of changing yield attributes in the Holstein breed, by applying current production data to a bio economic model it has been shown that the previous conclusions remain applicable in the prevailing circumstances.

The reason for shorter VWPs delivering enhanced financial value for higher yielding animals is based upon the increased levels of mean milk production per day as indicated from the production model. Reviewing the derivation for milk per day of ici from Results 3.2.2 we can observe that for TDYs at days 50 – 60pp below 25.35kg, mean daily production increases with increasing lactation length but for TDYs above that level mean daily production is inversely related to the ici. Hence the highest mean daily production is achieved by animals with least days open and highest TDYs whilst the observation from the data that lower yielding animals have higher mean production with increasing lactation length is reflected in the modelling. These mean yield effects in animals with high TDYs appear to contradict the perceived impact of early gestation upon yield (Olori et al, 1997; Lee et al, 1997) further contradictory effects are evident when taking into consideration that shorter lactations have a higher ratio of dry period days to production. Taking into account these two effects it must be assumed that the impact of extended days open is to cause prolonged periods of lower production levels in late lactation negating any additional production resulting from later conception.

This may be countered by animals with enhanced persistency, Arbel et al (2001) stated that *Milk production level and lactation persistency are crucial factors in determining the appropriate CI* indicating that animals with higher persistency levels may be more profitable in extended lactations. However Albarrán-Portillo and Pollott (2013) indicate that higher persistency is often associated with lower initial yields, similar effects are quoted by Dobson et al, (2007). For economic analysis the question which this generates is how is persistency measured? If the persistency attribute is based upon proportion of peak yield then effectively late lactation production volume per day may not be dissimilar between animals with a high peak and showing a lower relative proportion in late lactation than those with a lower peak but with higher persistency levels. In the discussion of optimal days open or VWPs it has been suggested that VWP's are unique at individual animal level (Inchaisri et al, 2011; Arbel et al, 2001) based upon persistency levels. To achieve this a mechanism would be required to attribute levels of persistency with suitable accuracy but there needs to be consideration that breeding animals for higher persistency, if based upon lower peak yields, may reduce overall milk sales per day against a high yielding animal exhibiting good fertility. Although it is recognised that higher yielding animals require more services per conception on average (Albarrán-Portillo and Pollott, 2013; Lee et al, 1997), Ouweltjes et al (1996) indicated that many high yielding animals do combine production with good reproductive performance suggesting that the combination is both sustainable and that there is a pool of potential breeding stock that can deliver the replacement requirements for high production dairy farming. This would be analogous to the breeding program undertaken across the Scandinavian red breeds where fertility has remained uncompromised (Berglund,2008). Fertility and lifetime traits are strongly weighted in the most recent UK amalgamated breeding index (£PLI), Lucy (2001)suggested that as these qualities return to the breed there may be a case for individually tailored breeding programs, these results may indicate that across the majority of Holstein herds early recommencement of breeding would continue to be financially advantageous. However if future breeding programs do increase persistency in high yielding animals and this is accompanied by improvements in both fertility and longevity, then by quantifying these attributes early in animal life through genomic profiling, it may lead to a change in dynamics such that individually tailored reproduction programs are optimal and practical.

The analysis was designed to simulate a basic margin per cow figure by including feed and replacement costs with calf, cull and production income. The results generated are in agreement with Ferguson and Skidmore (2009) in that extended days open cause a drop in gross margin, Sørensen and Østergaard (2003) indicated that a delay in insemination of 70 days would reduce herd profitability by 3% in herd with good reproductive performance. Conversely Arbel et al (2001) indicated that extending lactation increased margins but his work differed from the others by inclusion of part of the next lactation. This raises an important question on all analysis of these types, how do we assess the effects of previous reproductive performance in the current lactation? These results indicate that, for many tiers of production, the economic variability between short and long VWP were of relatively low order which would suggest that if any effects of early conception are observed in the subsequent lactation then the advantages of early rebreeding may be marginal. Research by Arbel et al (2001)was designed to address this situation and indicated negative correlations between income and early breeding however Sørensen and Østergaard (2003) applied the same production profile attributes in their work but the results conversely suggested that extended days open reduced profit.

A further consideration on the viability of short VWPs, particularly where the herd attributes would indicate marginal benefits, is reproductive performance. This work made no assumption on variability of CR associated with increasing days post partum and improving CR although there is evidence of such effects in the literature (Lucy, 2001; Inchaisri et al, 2010; Ouweltjes et al, 1996). Ferguson and Skidmore (2009) indicated that submission rates in early lactation were very similar but that CR may be compromised, this would directly affect pregnancy rates. Sufficient or accurate detail would not be available from the data analysis to estimate such effects in the sample group due to the inconsistent nature of service records in secondary data, it was not considered that any other work would give a suitable mechanism to apply variable CR within the model hence flat CR were applied across all periods of calving to service interval. The standard insemination cost applied was £25, taken over a 400 day CI would equate to 6.25p per day, if lower CR were confirmed for very early service then a proportion of this would need to be considered as additional cost however any mechanism for doing so may need to discriminate on both submission and CR. Table 9 indicates that these results are consistent with Ferguson and Skidmore, (2009) which indicated that herds which applied longer VWP and exhibited higher pregnancy rates delivered reduced economic value due to the extended interval to first service.

| Test Day Yield Level | pregnancy rate | Voluntary Waiting Period Length | Disposal Rate | income per day | Intercalving Interval |
|---|---|---|---|---|---|
| 52 | 17.5 | 30 | 33 | £2.83 | 381 |
| 52 | 22.5 | 60 | 33 | £2.81 | 395 |

Table 9 Comparison of the effects of extended VWP and improved pregnancy rates on overall output

The above results would indicate that, for the highest yielding herds, rebreeding later to take advantage of perceived improvements in CR may not be optimal. The potential effects of early service CR and effects on the next lactation need to be considered as part of a wider review of these results, although his project did not include analysis of these areas further research would be beneficial to complement this work.

For higher yielding herds the results indicate that managing for the least days open is economically advantageous, Meadows et al (2005) indicated that a CI of 12.5 months was optimal showing the importance of an early resumption of breeding to achieve the required average 100 day conception target. That work also indicated that the variable effects of increasing days open with decreasing comparative effect as days open increased, these results show similar variation on differentials between increasing length of VWP and income per day although of low order.

These results also show that as yield level decreases the economic significance of early rebreeding reduces, results which are aligned with the modelling completed by Inchaisri et al, (2011). This highlights a key observation as any strategy to improve reproductive performance which increase costs may not be advantageous in lower yielding herds. The conclusion is in agreement with Inchaisri et al (2011) in that shorter VWPs may improve returns but are not that significant compared to other economic factors. The length of VWP is significant in that it is the single factor that is completely within the control of the herd manager thus making it a unique feature of herd management.

### 4.2.2 Replacement and Pregnancy rate effects

The other factors considered were replacement rate (RR) and pregnancy rate (PR). RR was consistently the dominant factor affecting income per kg as indicated in the pie charts (Figure 11). Comparatively the overall significance of RR reduced with increasing yield due to dilution effects of the associated fixed costs however RR had greater influence than the combined effects of both pregnancy rate and VWP at all yield levels. These results are not in agreement with Inchaisri et al (2010) modelling which indicated that CR had the greatest economic significance, that model linked cull and fertility rates so poorer fertility may have had direct influence on replacement costs. These results concurred with those of Meadows et al (2005) who indicated that reduced RR was preferable including instances where increased days open were a result. The heat graphs (Figure 12) present this relationship, for all levels of production analysed reducing RR with fixed pregnancy rate increases income per day however with increasing yield levels PR assumes greater economic significance. The diagonal banding on the 52kg heat graph indicates that similar performance is achievable where decreasing PR is matched with a proportional reduction in RR, the 52kg TDY analysis showing that each percentage reduction in RR is equivalent to 3p per cow per day increased income while each percentage increase in PR generates approximately 0.8p per day. If it is accepted that CR are lower to earlier services (Lucy, 2001; Inchaisri et al, 2011, Ouweltjes et al, 1996, Ferguson and Skidmore, 2009), particularly in the highest yielding animals, then serving longer should not compromise PR but would lead to a reduction RR, a deduction from this being that extension of the maximum service date to induce these two effects may be optimal for some units.

If no consideration is given to variation in CR by stage of lactation then 2 different strategies to improve financial performance may be discussed. First, application of a maximum service date can be used to reduce CI and improve output per day. This may lead to small increases in PR where repeated serving of truly infertile animals is avoided, however the impact upon RR of this through increasing involuntary culls would need careful consideration. This strategy is associated with maximum milk sales through short CI and improvement of herd fertility as a result of replacements being produced only from cows matching high levels of production and good reproductive performance. Ferguson and Skidmore (2009) showed that herds applying this strategy had higher cull rates, lower average conception days but enhanced output whilst Stott et al, (1999) indicated that the cost of accepting more services was increasing days open and reduced income.

Alternatively, the use of longer service periods before fertility culls are selected would reduce RR but increase CI, in respect of production there would be a decrease in mean daily yield complimented by reducing replacement costs. This may be relevant on units where herds are closed and land is limited hence there is a compromise between heifer rearing space and the number of productive animals to be held on the same area, reduction of the latter leading to lower sales. The two sets of circumstances discussed would suggest that applying a strategy of a maximum service date or number of services to produce dairy heifers should lead to breeding selection from more fertile animals whilst a continuation of breeding to terminal sires up to a later cut off point will assist in keeping RR lower. Overall this would indicate that there is probably no one optimal rebreeding strategy as unique herd solutions based upon local conditions will be more applicable however a maximum service date combined with short VWP would be expected to be optimal across the majority of high production dairies.

As yield levels reduce, the dynamic between PR and RR becomes less significant (the slope of the contours on the heat graphs tend to infinity indicating the reducing effect of PR with reducing yield levels) such that any strategy to reduce RR would be beneficial. This is direct result of the lactation data used in the modelling, the inference from that data would be that extension of CI leads to increased income per day in low yielding animals hence any management factors that have a reducing effect on lactation length (VWP, PR) appear to offer little benefit.

As indicated by Inchaisri et al (2011), there is a compromise between RR and PR, Meadows et al (2005) suggested that RR would increase as reproductive performance declines which is logical however, in terms of analysis of actual performance, reproductive performance metrics will show a decline where continued serving is deployed to reduce RR, in these instances RR reduces and reproductive performance measures decline also. This work would indicate that the economic significance of such a strategy is variable and directly correlated to production levels.

### 4.2.3 Closing discussion of results

The results and associated discussion highlight the complexity of the inter relationships between fertility factors, replacement rate and yield level in the wider analysis of optimal performance. The relative importance of the management factors vary according to yield, it is notable that delivery of good reproductive performance is of greatest value in high yielding animals. This is in broad agreement with similar previous related works however the wider importance to the industry is reinforcement of the relevance of those basic management principles within the context of prevailing production conditions. The observed changes in lactation profiles combined with the advances in nutritional science exploiting these genetic characteristics has certainly led to a position where there is a belief that extension of lactation does not impact upon efficiency, these results indicate that is not the case. In their introduction, Inchaisri et al (2011) indicated that there were farmers in Holland that perceived that reproductive efficiency had become less important, it was observation of similar attitudes amongst UK farmers which gave the premise for this research. This results of this research should be used to bring focus back to the importance of fertility in overall production efficiency.

It is interesting to note that the model could be further refined to be used as a decision support tool for consultants or directly for farmers who require a cost benefit analysis for either change in management policy or budgeting for capital expenditure. The production modelling could be enhanced by use of BLUP principles such that accurate modelling could be produced for any given production scenario. The yield modelling in this research was fit for purpose in respect of the homogenous nature of the data however for use at individual herd level the production analytics would require enhancement. By replacing the basic calculation of yield from a given set of parameters with direct modelling of the coefficients of change across various parameters within yield strata, it is perceivable that the model could use herd information extracted through a data import system from software or milk recording. This would enable use of individual records within the herd to compute the value of changes in reproductive and production characteristics for any unit enabling decision support for capital expenditure, analysing changes to yield levels or milk contract comparisons. The principles of using recorded farm data to model future performance is already available for physical factors (Interherd plus, Pan agriculture and University of Reading) however full data imports to measure or use in predictive economic planning is unavailable and should be considered. The quantity of data available to develop and utilise in such systems is a relatively recent phenomena, making use of “big data” will be of greater importance as the global requirements for greater quantities of cheaper food impact upon the industry.

One key area which was not considered for direct analysis but has a fundamental effect upon income is the price obtained for the end product. This major factor in herd profitability was not considered for sensitivity analysis as it is unique in respect of being outside of the control of the individual business hence not affected by any of the management and performance factors assessed in this work. However, it does need addressing within the discussion to illustrate overall significance. For example, taking the 52kg TDY performance evaluation we can observe that the best performance was obtained by the highest PR (22.5%), lowest replacement rate (25%) and shortest VWP (30 days), this gave a mean income figure of £3.20 per day, if we take the same yield level but exhibiting the poorest performance in respect of the parameters previously mentioned, the result is a mean income per day of £2.84 hence giving a difference between these two performance levels of 36p per cow per day. To contextualise the comparative effect of milk price we can apply the mean milk per day formula as shown in section 9,

$$M\ ici = 19.22-0.1074TDY+0.003249TDY^2 + (130.9TDY - 3200)/L$$

with TDY = 52 and caving interval (L) = 400 days giving a mean daily production of 31.44kg, a direct result from this being that a 1p increment in milk price would be equivalent to a 31.4p change in income per day. This example indicates that the enhancement in economic performance given by the best management practice is relatively small against the effects of variation in the milk price. Milk price is the dominant factor in dairy economics, although the management areas reviewed in this analysis have comparatively small effects they do present opportunities to improve the financial results within the framework of the prevailing price structure.

## 5 Conclusions

In conclusion, this work has shown that replacement rate is the single most influential factor on herd economics regardless of yield level and reproductive performance. Replacement rates are difficult to manipulate however the true economic significance may not necessarily be recognised across some sectors of the industry and unnecessary losses accepted where minor investment may offer good return.

Pregnancy rates were the second most important factor highlighting the importance of reproductive performance on herd economics. It can be concluded from this that optimisation of heat detection offers a mechanism to improve herd income because conception rates, which are the secondary factor in pregnancy rate, offer little scope for manipulation.

These dynamics create a dilemma for herd management decisions where extension of the breeding interval may reduce replacement rates but increase average days in milk as a result. There is a balance between the two which would be optimal but local economic , physical and aspirational factors mean that this is probably unique for every herd and would be difficult to establish.

The one factor that is completely controlled by herd management is that of voluntary waiting period. Short voluntary waiting periods are economically advantageous across almost all yield levels and offer some solutions in addressing the above dilemma by offering extension of the breeding interval through earlier service as opposed to increasing service periods.

This work would suggest that improving fertility should be the primary consideration in future Holstein breeding selection; reduction of average days in milk combined with reduced involuntary culls would offer significant economic advantage at all levels of production.

# 6 Appendices

## 6.1 Results tables

The tables published below contain edited results sets used to show the changing relationships between the factors under analysis, the other variables and the output value. The full results are shown in table A4 without any further analysis but may be used for reference purposes.

### 6.1.1 Voluntary Waiting Period

| Test Day Yield Level | pregnancy rate | Disposal Rate | income per day | Value change for 60 day vs 40 day VWP |
|---|---|---|---|---|
| 28 | 12.5 | 25 | £1.59 | £0.01 |
| 28 | 12.5 | 33 | £1.32 | £0.03 |
| 28 | 17.5 | 25 | £1.59 | £0.02 |
| 28 | 17.5 | 33 | £1.32 | £0.04 |
| 28 | 22.5 | 25 | £1.61 | £0.02 |
| 28 | 22.5 | 33 | £1.32 | £0.03 |
| 36 | 12.5 | 25 | £1.90 | -£0.01 |
| 36 | 12.5 | 33 | £1.63 | £0.00 |
| 36 | 17.5 | 25 | £1.93 | -£0.02 |
| 36 | 17.5 | 33 | £1.67 | -£0.01 |
| 36 | 22.5 | 25 | £1.98 | -£0.02 |
| 36 | 22.5 | 33 | £1.71 | -£0.01 |
| 44 | 12.5 | 25 | £2.32 | -£0.04 |
| 44 | 12.5 | 33 | £2.06 | -£0.03 |
| 44 | 17.5 | 25 | £2.39 | -£0.05 |
| 44 | 17.5 | 33 | £2.15 | -£0.04 |
| 44 | 22.5 | 25 | £2.47 | -£0.06 |
| 44 | 22.5 | 33 | £2.21 | -£0.05 |
| 52 | 12.5 | 25 | £2.84 | -£0.07 |
| 52 | 12.5 | 33 | £2.58 | -£0.07 |
| 52 | 17.5 | 25 | £2.95 | -£0.08 |
| 52 | 17.5 | 33 | £2.72 | -£0.07 |
| 52 | 22.5 | 25 | £3.06 | -£0.09 |
| 52 | 22.5 | 33 | £2.81 | -£0.08 |

Table A1. A selection of results and comparison of income levels for 2 lengths of voluntary waiting period

### 6.1.2 Pregnancy Rate

| Test Day Yield Level | Voluntary Waiting Period Length | Disposal Rate | income per day | Value change; 22.5% vs 12.5% Pregnancy Rate |
|---|---|---|---|---|
| 28 | 30 | 25 | £1.58 | £0.01 |
| 28 | 30 | 33 | £1.27 | £0.00 |
| 28 | 40 | 25 | £1.59 | £0.01 |
| 28 | 40 | 33 | £1.29 | £0.00 |
| 28 | 50 | 25 | £1.60 | £0.02 |
| 28 | 50 | 33 | £1.31 | £0.00 |
| 28 | 60 | 25 | £1.61 | £0.02 |
| 28 | 60 | 33 | £1.32 | £0.00 |
| 40 | 30 | 25 | £2.27 | £0.14 |
| 40 | 30 | 33 | £1.98 | £0.12 |
| 40 | 40 | 25 | £2.25 | £0.13 |
| 40 | 40 | 33 | £1.97 | £0.12 |
| 40 | 50 | 25 | £2.23 | £0.12 |
| 40 | 50 | 33 | £1.95 | £0.11 |
| 40 | 60 | 25 | £2.21 | £0.12 |
| 40 | 60 | 33 | £1.94 | £0.11 |
| 52 | 30 | 25 | £3.20 | £0.25 |
| 52 | 30 | 33 | £2.94 | £0.26 |
| 52 | 40 | 25 | £3.15 | £0.24 |
| 52 | 40 | 33 | £2.89 | £0.24 |
| 52 | 50 | 25 | £3.10 | £0.23 |
| 52 | 50 | 33 | £2.85 | £0.23 |
| 52 | 60 | 25 | £3.06 | £0.22 |
| 52 | 60 | 33 | £2.81 | £0.23 |

Table A2. A selection of results and comparison of income levels for 2 levels of pregnancy rate

### 6.1.3 Replacement Rate

| Test Day Yield Level | pregnancy rate | Voluntary Waiting Period Length | income per day | Intercalving Interval | Income differential, 25% vs 33% replacement rate |
|---|---|---|---|---|---|
| 28 | 12.5 | 30 | £1.57 | 422 | £0.30 |
| 28 | 17.5 | 30 | £1.56 | 389 | £0.29 |
| 28 | 22.5 | 30 | £1.58 | 371 | £0.31 |
| 28 | 12.5 | 40 | £1.58 | 432 | £0.29 |
| 28 | 17.5 | 40 | £1.57 | 399 | £0.29 |
| 28 | 22.5 | 40 | £1.59 | 381 | £0.30 |
| 28 | 12.5 | 50 | £1.58 | 442 | £0.27 |
| 28 | 17.5 | 50 | £1.58 | 409 | £0.28 |
| 28 | 22.5 | 50 | £1.60 | 391 | £0.29 |
| 28 | 12.5 | 60 | £1.59 | 452 | £0.27 |
| 28 | 17.5 | 60 | £1.59 | 419 | £0.27 |
| 28 | 22.5 | 60 | £1.61 | 401 | £0.29 |
| 40 | 12.5 | 30 | £2.13 | 422 | £0.27 |
| 40 | 17.5 | 30 | £2.20 | 389 | £0.27 |
| 40 | 22.5 | 30 | £2.27 | 371 | £0.29 |
| 40 | 12.5 | 40 | £2.12 | 432 | £0.27 |
| 40 | 17.5 | 40 | £2.18 | 399 | £0.27 |
| 40 | 22.5 | 40 | £2.25 | 381 | £0.28 |
| 40 | 12.5 | 50 | £2.11 | 442 | £0.27 |
| 40 | 17.5 | 50 | £2.16 | 409 | £0.26 |
| 40 | 22.5 | 50 | £2.23 | 391 | £0.28 |
| 40 | 12.5 | 60 | £2.09 | 452 | £0.26 |
| 40 | 17.5 | 60 | £2.14 | 419 | £0.25 |
| 40 | 22.5 | 60 | £2.21 | 401 | £0.27 |
| 52 | 12.5 | 30 | £2.95 | 422 | £0.27 |
| 52 | 17.5 | 30 | £3.08 | 389 | £0.25 |
| 52 | 22.5 | 30 | £3.20 | 371 | £0.26 |
| 52 | 12.5 | 40 | £2.91 | 432 | £0.26 |
| 52 | 17.5 | 40 | £3.03 | 399 | £0.24 |
| 52 | 22.5 | 40 | £3.15 | 381 | £0.26 |
| 52 | 12.5 | 50 | £2.87 | 442 | £0.25 |
| 52 | 17.5 | 50 | £2.99 | 409 | £0.24 |
| 52 | 22.5 | 50 | £3.10 | 391 | £0.25 |
| 52 | 12.5 | 60 | £2.84 | 452 | £0.26 |
| 52 | 17.5 | 60 | £2.95 | 419 | £0.23 |
| 52 | 22.5 | 60 | £3.06 | 401 | £0.25 |

Table A3. A selection of results and comparison of income levels for 2 levels

### 6.1.4 Complete results

| Test Day Yield Level | pregnancy rate | Voluntary Waiting Period Length | Disposal Rate | income per day | Intercalving Interval |
|---|---|---|---|---|---|
| 24 | 12.5 | 30 | 25 | £1.44 | 422 |
| 24 | 12.5 | 40 | 25 | £1.45 | 432 |
| 24 | 12.5 | 50 | 25 | £1.46 | 442 |
| 24 | 12.5 | 60 | 25 | £1.48 | 452 |
| 24 | 17.5 | 30 | 25 | £1.40 | 389 |
| 24 | 17.5 | 40 | 25 | £1.42 | 399 |
| 24 | 17.5 | 50 | 25 | £1.44 | 409 |
| 24 | 17.5 | 60 | 25 | £1.45 | 419 |
| 24 | 22.5 | 30 | 25 | £1.40 | 371 |
| 24 | 22.5 | 40 | 25 | £1.42 | 381 |
| 24 | 22.5 | 50 | 25 | £1.44 | 391 |
| 24 | 22.5 | 60 | 25 | £1.46 | 401 |
| 24 | 12.5 | 30 | 33 | £1.13 | 410 |
| 24 | 12.5 | 40 | 33 | £1.16 | 420 |
| 24 | 12.5 | 50 | 33 | £1.18 | 430 |
| 24 | 12.5 | 60 | 33 | £1.20 | 440 |
| 24 | 17.5 | 30 | 33 | £1.10 | 381 |
| 24 | 17.5 | 40 | 33 | £1.13 | 391 |
| 24 | 17.5 | 50 | 33 | £1.15 | 401 |
| 24 | 17.5 | 60 | 33 | £1.18 | 411 |
| 24 | 22.5 | 30 | 33 | £1.09 | 365 |
| 24 | 22.5 | 40 | 33 | £1.12 | 375 |
| 24 | 22.5 | 50 | 33 | £1.14 | 385 |
| 24 | 22.5 | 60 | 33 | £1.17 | 395 |
| 28 | 12.5 | 30 | 25 | £1.57 | 422 |
| 28 | 12.5 | 40 | 25 | £1.58 | 432 |
| 28 | 12.5 | 50 | 25 | £1.58 | 442 |
| 28 | 12.5 | 60 | 25 | £1.59 | 452 |
| 28 | 17.5 | 30 | 25 | £1.56 | 389 |
| 28 | 17.5 | 40 | 25 | £1.57 | 399 |
| 28 | 17.5 | 50 | 25 | £1.58 | 409 |
| 28 | 17.5 | 60 | 25 | £1.59 | 419 |
| 28 | 22.5 | 30 | 25 | £1.58 | 371 |
| 28 | 22.5 | 40 | 25 | £1.59 | 381 |
| 28 | 22.5 | 50 | 25 | £1.60 | 391 |
| 28 | 22.5 | 60 | 25 | £1.61 | 401 |

| Test Day Yield Level | pregnancy rate | Voluntary Waiting Period Length | Disposal Rate | income per day | Intercalving Interval |
|---|---|---|---|---|---|
| 28 | 12.5 | 30 | 33 | £1.27 | 410 |
| 28 | 12.5 | 40 | 33 | £1.29 | 420 |
| 28 | 12.5 | 50 | 33 | £1.31 | 430 |
| 28 | 12.5 | 60 | 33 | £1.32 | 440 |
| 28 | 17.5 | 30 | 33 | £1.27 | 381 |
| 28 | 17.5 | 40 | 33 | £1.28 | 391 |
| 28 | 17.5 | 50 | 33 | £1.30 | 401 |
| 28 | 17.5 | 60 | 33 | £1.32 | 411 |
| 28 | 22.5 | 30 | 33 | £1.27 | 365 |
| 28 | 22.5 | 40 | 33 | £1.29 | 375 |
| 28 | 22.5 | 50 | 33 | £1.31 | 385 |
| 28 | 22.5 | 60 | 33 | £1.32 | 395 |
| 32 | 12.5 | 30 | 25 | £1.73 | 422 |
| 32 | 12.5 | 40 | 25 | £1.73 | 432 |
| 32 | 12.5 | 50 | 25 | £1.73 | 442 |
| 32 | 12.5 | 60 | 25 | £1.73 | 452 |
| 32 | 17.5 | 30 | 25 | £1.75 | 389 |
| 32 | 17.5 | 40 | 25 | £1.75 | 399 |
| 32 | 17.5 | 50 | 25 | £1.75 | 409 |
| 32 | 17.5 | 60 | 25 | £1.75 | 419 |
| 32 | 22.5 | 30 | 25 | £1.78 | 371 |
| 32 | 22.5 | 40 | 25 | £1.78 | 381 |
| 32 | 22.5 | 50 | 25 | £1.78 | 391 |
| 32 | 22.5 | 60 | 25 | £1.78 | 401 |
| 32 | 12.5 | 30 | 33 | £1.44 | 410 |
| 32 | 12.5 | 40 | 33 | £1.45 | 420 |
| 32 | 12.5 | 50 | 33 | £1.46 | 430 |
| 32 | 12.5 | 60 | 33 | £1.46 | 440 |
| 32 | 17.5 | 30 | 33 | £1.46 | 381 |
| 32 | 17.5 | 40 | 33 | £1.47 | 391 |
| 32 | 17.5 | 50 | 33 | £1.47 | 401 |
| 32 | 17.5 | 60 | 33 | £1.48 | 411 |
| 32 | 22.5 | 30 | 33 | £1.48 | 365 |
| 32 | 22.5 | 40 | 33 | £1.49 | 375 |
| 32 | 22.5 | 50 | 33 | £1.50 | 385 |
| 32 | 22.5 | 60 | 33 | £1.50 | 395 |

| Test Day Yield Level | pregnancy rate | Voluntary Waiting Period Length | Disposal Rate | income per day | Intercalving Interval |
|---|---|---|---|---|---|
| 36 | 12.5 | 30 | 25 | £1.92 | 422 |
| 36 | 12.5 | 40 | 25 | £1.91 | 432 |
| 36 | 12.5 | 50 | 25 | £1.91 | 442 |
| 36 | 12.5 | 60 | 25 | £1.90 | 452 |
| 36 | 17.5 | 30 | 25 | £1.96 | 389 |
| 36 | 17.5 | 40 | 25 | £1.95 | 399 |
| 36 | 17.5 | 50 | 25 | £1.94 | 409 |
| 36 | 17.5 | 60 | 25 | £1.93 | 419 |
| 36 | 22.5 | 30 | 25 | £2.01 | 371 |
| 36 | 22.5 | 40 | 25 | £2.00 | 381 |
| 36 | 22.5 | 50 | 25 | £1.99 | 391 |
| 36 | 22.5 | 60 | 25 | £1.98 | 401 |
| 36 | 12.5 | 30 | 33 | £1.64 | 410 |
| 36 | 12.5 | 40 | 33 | £1.63 | 420 |
| 36 | 12.5 | 50 | 33 | £1.63 | 430 |
| 36 | 12.5 | 60 | 33 | £1.63 | 440 |
| 36 | 17.5 | 30 | 33 | £1.68 | 381 |
| 36 | 17.5 | 40 | 33 | £1.68 | 391 |
| 36 | 17.5 | 50 | 33 | £1.68 | 401 |
| 36 | 17.5 | 60 | 33 | £1.67 | 411 |
| 36 | 22.5 | 30 | 33 | £1.72 | 365 |
| 36 | 22.5 | 40 | 33 | £1.72 | 375 |
| 36 | 22.5 | 50 | 33 | £1.71 | 385 |
| 36 | 22.5 | 60 | 33 | £1.71 | 395 |
| 40 | 12.5 | 30 | 25 | £2.13 | 422 |
| 40 | 12.5 | 40 | 25 | £2.12 | 432 |
| 40 | 12.5 | 50 | 25 | £2.11 | 442 |
| 40 | 12.5 | 60 | 25 | £2.09 | 452 |
| 40 | 17.5 | 30 | 25 | £2.20 | 389 |
| 40 | 17.5 | 40 | 25 | £2.18 | 399 |
| 40 | 17.5 | 50 | 25 | £2.16 | 409 |
| 40 | 17.5 | 60 | 25 | £2.14 | 419 |
| 40 | 22.5 | 30 | 25 | £2.27 | 371 |
| 40 | 22.5 | 40 | 25 | £2.25 | 381 |
| 40 | 22.5 | 50 | 25 | £2.23 | 391 |
| 40 | 22.5 | 60 | 25 | £2.21 | 401 |

| Test Day Yield Level | pregnancy rate | Voluntary Waiting Period Length | Disposal Rate | income per day | Intercalving Interval |
|---|---|---|---|---|---|
| 40 | 12.5 | 30 | 33 | £1.86 | 410 |
| 40 | 12.5 | 40 | 33 | £1.85 | 420 |
| 40 | 12.5 | 50 | 33 | £1.84 | 430 |
| 40 | 12.5 | 60 | 33 | £1.83 | 440 |
| 40 | 17.5 | 30 | 33 | £1.93 | 381 |
| 40 | 17.5 | 40 | 33 | £1.91 | 391 |
| 40 | 17.5 | 50 | 33 | £1.90 | 401 |
| 40 | 17.5 | 60 | 33 | £1.89 | 411 |
| 40 | 22.5 | 30 | 33 | £1.98 | 365 |
| 40 | 22.5 | 40 | 33 | £1.97 | 375 |
| 40 | 22.5 | 50 | 33 | £1.95 | 385 |
| 40 | 22.5 | 60 | 33 | £1.94 | 395 |
| 44 | 12.5 | 30 | 25 | £2.39 | 422 |
| 44 | 12.5 | 40 | 25 | £2.36 | 432 |
| 44 | 12.5 | 50 | 25 | £2.34 | 442 |
| 44 | 12.5 | 60 | 25 | £2.32 | 452 |
| 44 | 17.5 | 30 | 25 | £2.47 | 389 |
| 44 | 17.5 | 40 | 25 | £2.44 | 399 |
| 44 | 17.5 | 50 | 25 | £2.42 | 406 |
| 44 | 17.5 | 60 | 25 | £2.39 | 419 |
| 44 | 22.5 | 30 | 25 | £2.56 | 371 |
| 44 | 22.5 | 40 | 25 | £2.53 | 381 |
| 44 | 22.5 | 50 | 25 | £2.50 | 391 |
| 44 | 22.5 | 60 | 25 | £2.47 | 401 |
| 44 | 12.5 | 30 | 33 | £2.11 | 410 |
| 44 | 12.5 | 40 | 33 | £2.09 | 420 |
| 44 | 12.5 | 50 | 33 | £2.08 | 430 |
| 44 | 12.5 | 60 | 33 | £2.06 | 440 |
| 44 | 17.5 | 30 | 33 | £2.21 | 381 |
| 44 | 17.5 | 40 | 33 | £2.19 | 391 |
| 44 | 17.5 | 50 | 33 | £2.17 | 401 |
| 44 | 17.5 | 60 | 33 | £2.15 | 411 |
| 44 | 22.5 | 30 | 33 | £2.28 | 365 |
| 44 | 22.5 | 40 | 33 | £2.26 | 375 |
| 44 | 22.5 | 50 | 33 | £2.23 | 385 |
| 44 | 22.5 | 60 | 33 | £2.21 | 395 |

| Test Day Yield Level | pregnancy rate | Voluntary Waiting Period Length | Disposal Rate | income per day | Intercalving Interval |
|---|---|---|---|---|---|
| 48 | 12.5 | 30 | 25 | £2.65 | 422 |
| 48 | 12.5 | 40 | 25 | £2.62 | 432 |
| 48 | 12.5 | 50 | 25 | £2.59 | 442 |
| 48 | 12.5 | 60 | 25 | £2.57 | 452 |
| 48 | 17.5 | 30 | 25 | £2.76 | 389 |
| 48 | 17.5 | 40 | 25 | £2.73 | 399 |
| 48 | 17.5 | 50 | 25 | £2.69 | 409 |
| 48 | 17.5 | 60 | 25 | £2.66 | 419 |
| 48 | 22.5 | 30 | 25 | £2.87 | 371 |
| 48 | 22.5 | 40 | 25 | £2.83 | 381 |
| 48 | 22.5 | 50 | 25 | £2.79 | 391 |
| 48 | 22.5 | 60 | 25 | £2.75 | 401 |
| 48 | 12.5 | 30 | 33 | £2.38 | 410 |
| 48 | 12.5 | 40 | 33 | £2.36 | 420 |
| 48 | 12.5 | 50 | 33 | £2.33 | 430 |
| 48 | 12.5 | 60 | 33 | £2.31 | 440 |
| 48 | 17.5 | 30 | 33 | £2.51 | 381 |
| 48 | 17.5 | 40 | 33 | £2.48 | 391 |
| 48 | 17.5 | 50 | 33 | £2.45 | 401 |
| 48 | 17.5 | 60 | 33 | £2.42 | 411 |
| 48 | 22.5 | 30 | 33 | £2.59 | 365 |
| 48 | 22.5 | 40 | 33 | £2.56 | 375 |
| 48 | 22.5 | 50 | 33 | £2.53 | 385 |
| 48 | 22.5 | 60 | 33 | £2.50 | 395 |
| 52 | 12.5 | 30 | 25 | £2.95 | 422 |
| 52 | 12.5 | 40 | 25 | £2.91 | 432 |
| 52 | 12.5 | 50 | 25 | £2.87 | 442 |
| 52 | 12.5 | 60 | 25 | £2.84 | 452 |
| 52 | 17.5 | 30 | 25 | £3.08 | 389 |
| 52 | 17.5 | 40 | 25 | £3.03 | 399 |
| 52 | 17.5 | 50 | 25 | £2.99 | 409 |
| 52 | 17.5 | 60 | 25 | £2.95 | 419 |
| 52 | 22.5 | 30 | 25 | £3.20 | 371 |
| 52 | 22.5 | 40 | 25 | £3.15 | 381 |
| 52 | 22.5 | 50 | 25 | £3.10 | 391 |
| 52 | 22.5 | 60 | 25 | £3.06 | 401 |

| Test Day Yield Level | pregnancy rate | Voluntary Waiting Period Length | Disposal Rate | income per day | Intercalving Interval |
|---|---|---|---|---|---|
| 52 | 12.5 | 30 | 33 | £2.68 | 410 |
| 52 | 12.5 | 40 | 33 | £2.65 | 420 |
| 52 | 12.5 | 50 | 33 | £2.62 | 430 |
| 52 | 12.5 | 60 | 33 | £2.58 | 440 |
| 52 | 17.5 | 30 | 33 | £2.83 | 381 |
| 52 | 17.5 | 40 | 33 | £2.79 | 391 |
| 52 | 17.5 | 50 | 33 | £2.75 | 401 |
| 52 | 17.5 | 60 | 33 | £2.72 | 411 |
| 52 | 22.5 | 30 | 33 | £2.94 | 365 |
| 52 | 22.5 | 40 | 33 | £2.89 | 375 |
| 52 | 22.5 | 50 | 33 | £2.85 | 385 |
| 52 | 22.5 | 60 | 33 | £2.81 | 395 |

Table A4 The complete results of the main analysis across the various parameters.

### 6.2 Theory behind termination of iterative model

*(1) Comparative termination of the iterative process;*

*Taking R to be RR/100 so R e ]0,1[ and, if required, x and y to be positive real numbers for comparative purposes*

*i)* $(1-R)^x=R$ *This is the numeric representation of the complete herd available then terminating after x iterations at the required replacement rate.*

*ii)* $(1-(R/2))^y=R/2$ *This represents commencing with half of the replacement rate removed and terminating after y iterations leaving half of the replacement rate.*

*From this;*

$(1-R)^x=2*(1-(R/2))^y$

giving $\frac{(1-R)^x}{(1-(R/2))^y}=2$, *But, for all R e ]0,1[* $1-R < 1-R/2$ *which implies that* $y>x$

### 6.3 Publications

#### 6.3.1 CARS conference abstract, presented June 2014

**Project title- Researching the financial impact of short voluntary waiting periods in Holstein herds**
Name- Richard Miller
Programme and stage- ResM Year 2 part time
School- *Biomedical and Biological Sciences*

**The potential relationship between yield evaluation and reducing fertility in Holstein dairy cattle**


Yield comparators are vital in the assessment of dairy breeding stock and constitute a major component of aggregate breeding selection indices across the world. Whilst the focus of these indices has moved from purely production to wider phenotypic evaluation, the liquid element of production remains one of the key comparators. The 305 day lactation total is the international metric for yield evaluation, however, with the increasing use of short calving to first service intervals, the most fertile cows fail to complete 305 days. Consequently, these animals record significantly lower yields than equivalent animals completing longer lactations, in addition this study also presents results which suggest that a continued increase in evaluation totals are recorded as overall lactation length increases

Lactation records of Holstein cows calving in the year ending May 2013 were obtained from NMR. This data set was discriminated over a range of parameters to ensure validity leaving 45604 records in the analysis set. Linear regression was applied to establish a test day weighing window that would provide a suitable prediction of lactation total from daily yield and then interval analysis applied to investigate both 305 day lactation totals and milk per day of inter-calving interval for cohorts set by test day yield.

The evidence provided in this study suggests that the current yield parameter may discriminate against shorter lactations which, by inference, is a bias against animals which encompass both high production and good fertility.

# Does the 305 day lactation total reflect dairy cow production potential?

**Implications** Yield comparators are vital in the assessment of dairy breeding stock at individual, herd, and breed level, they are also a major component of estimated breeding values across the world. The evidence provided in this study suggests that the currently used 305d milk yield may discriminate against shorter lactations which, by inference, is a bias against animals which encompass both high production and good fertility.

**Introduction** Whilst the focus of estimated breeding values has moved from purely production to wider phenotypic evaluation, the liquid element of dairy cow production remains one of the key comparators within the industry. 305 day lactation totals are the current international metric for yield evaluation, however, with the increasing use of short voluntary waiting periods, many cows do not complete the full 305 days. Consequently, these animals record significantly lower yields than equivalent animals completing longer lactations. This study presents results which suggest that a review of yield comparators may be required to ensure that individual animal records truly reflect their production potential.

**Material and methods** Lactation records of all Holstein Friesian animals calving in the year ending May 2013 were obtained from National Milk Records PLC. The data set was discriminated to include parities 2-8, age at first calving 20-40 months and animals completing more than 5 test day weighings. Due to the unreliable nature of service data, conception days post partum (pp) were calculated by counting back from the subsequent calving (Kadamideen et al, 2000). Calving intervals of less than 310 days were removed to reduce the influence of abortion or abnormal occurences and intervals of greater than 450 days were removed as they were not applicable to this study. Regression analysis was applied to establish a test day weighing window that would provide a suitable prediction of lactation total from daily yield (Table 1). This was found to be most representative between days 50 & 60 so the data was subdivided to reflect these results (n=45604) and interval analysis applied to investigate both 305 day lactation totals and milk per day of inter-calving interval (Table 2).

**Results**

Table 1

| Conception cohort | Regression of total lactation against test day yield (50-60 days pp) | R - Sq | N |
|---|---|---|---|
| 40-50 days pp | Lactation total (kg) = 998.2 + 193.2kg per kg test day yield (days 50-60pp) | 73.20% | 4831 |
| 70-80 days pp | Lactation total (kg) = 1575 + 193.1kg per kg of test day yield (days 50-60pp) | 66.90% | 4833 |
| 100-110 days pp | Lactation total (kg) = 1785 + 204.0kg per kg of test day yield (days 50-60pp) | 65.10% | 4430 |

Table 2

| Test day yield cohort | 30-35kg | | | 35-40kg | | | 40-45kg | | |
|---|---|---|---|---|---|---|---|---|---|
| Conception cohort (days pp) | Mean 305 day lactation | Mean milk / day intercalving interval | N | Mean 305 day lactation | Mean milk / day intercalving interval | N | Mean 305 day lactation | Mean milk / day intercalving interval | N |
| 30-49 | 7204 | 22.42 | 604 | 8192 | 25.44 | 654 | 9095 | 28.24 | 553 |
| 50-69 | 7564 | 22.31 | 1492 | 8582 | 25.3 | 1703 | 9470 | 27.9 | 1533 |
| 70-89 | 7814 | 21.99 | 1744 | 8832 | 24.83 | 1928 | 9754 | 27.44 | 1633 |
| 90-109 | 7986 | 21.81 | 1625 | 8986 | 24.53 | 1801 | 9987 | 27.3 | 1555 |
| 110-129 | 8072 | 21.52 | 1249 | 9088 | 24.2 | 1521 | 10043 | 26.77 | 1522 |
| 130-149 | 8190 | 21.42 | 1023 | 9183 | 23.99 | 1195 | 10142 | 26.53 | 1116 |
| 150-169 | 8298 | 21.22 | 800 | 9191 | 23.51 | 1026 | 10216 | 26.2 | 878 |

**Conclusion** The results indicate that animals which conceive very early in lactation show the highest levels of production when measured on milk per day of intercalving interval, as conception days pp increase there is a continuing decay in this measurement (range -5 to -7% across the yield cohorts). Conversely, as conception days pp increase there is a marked increase in the 305 day lactation total (range +12 to +15% across the yield cohorts). As conception days pp approach 85, this is driven by a continued increase of days in milk recorded until eventual completion of the full 305 days, after that point it is assumed that the continuing increase is due to the effect on lactation of later conception but this remains to be established. The results indicate a bias against those animals which are best suited to high yielding, intensive systems where strong production combined with early resumption of oestrus and subsequent conception are key to maximising output.

**Acknowledgements** National Milk Records PLC **References** Kadarmideen, H.N, Thompson, R., Simm, G. 2000 Anim. Sci. 71, 411–420.

# A preliminary investigation into the effect of using ICAR 305 day lactation figures as a parameter for breed selection

**Summary:** *(Your summary (times new roman) must use Body text style and must not be longer than this box)*

**Introduction.** Recent studies have reported an adverse correlation between high yields and reproductive performance in dairy cattle (Mackey, Gordon, McCoy, Verner, & Mayne, 2007), (Wicks & Leaver, 2004). It is estimated that infertility costs the UK dairy industry £500M annually, the consequences being both reduced income for farmers and increased cost to consumers where milk contract prices are based on cost of production. This study investigates whether the use of 305 day lactation total as a selection parameter may have led to selective breeding from less fertile animals. It is suggested that the volume production element of the breeding values discriminates against shorter periods between calving and conception resulting in the selection process being biased against the most fertile animals over multiple generations.

**Method.** Milk recording data (n=500) from five of the UK's leading herds was gathered. Herds were selected on the basis of peer recognition for technical standards, data quality and a herd average 305 day yield > 11000kg. Within the selected herds second lactation production was extracted from animals currently in their third and fourth lactation, this ensured that only animals which remained viable after the data was gathered were selected. Secondary data was used so it is assumed that the management and genetics were similar to achieve these high levels of production. Data was normally distributed; analysis was undertaken via linear regression. The independent variable, pre-service yield measured between days 20 – 50 was compared to dependent variables, days in milk at conception and 305 day lactation total. Further analysis of a sub-group (n=152) defined by pre-service yield mean ±2.5KG was performed. Linear regression analysis was carried out to investigate the effect of pre-service yield on days in milk at conception and the effects of both pre-service yield and the days in milk at conception on 305 day lactation total.

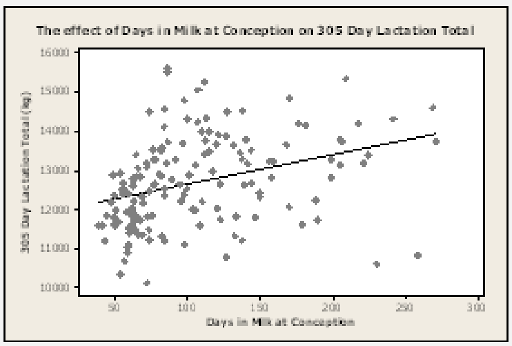



Figure 1, The regression analysis of 305 day lactation total against days in milk completed at conception

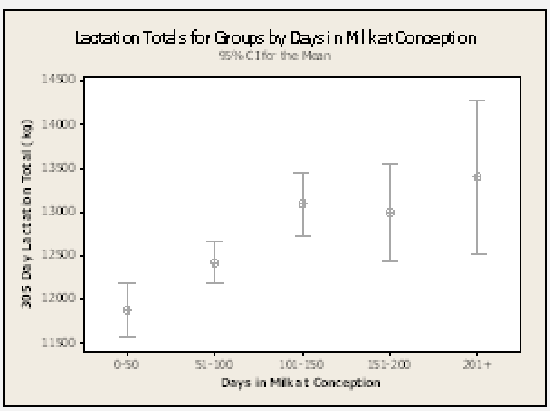



Figure 2, Interval analysis of 305 day lactation total against days in milk completed at conception

**Results.** The analysis was carried out on a subgroup of 152 animals which had pre service yields in the range 47–52 kg. The effect of the pre-service yield on days in milk at conception and gave a regression line of 176.9days–1.46 days per kg pre-service yield which indicated that the highest yielding cows conceived earlier. Had higher yielding cows conceived later, the implication would be that the higher production totals attributed to later conception would be due to the relative potential of the animals, this result challenges that assertion.

Figure 1 shows the regression analysis of 305 day lactation total against days in milk at conception. The results being 11906kg + 7.42kg per DIM conceived.

Figure 2 shows the same results as above as an interval plot. The number of animals in each sector (commencing at 0-50 days pp) are 11, 76, 39, 14 and 12 with mean 305 day yields 11868, 12419, 13088, 12988 and 13397 kg respectively

**Conclusions.** The results for the effect of pre-service yield on days post partum at conception indicate that higher yields were not significant in delaying conception within the study group. The figures demonstrate the effect of later conception on 305 day yield. Lower lactation yields are partly driven by cows which conceive at less than 76 days post partum failing to complete a 305 day lactation, however the continuation of increasing yields beyond this threshold indicates a potential cost in production of early conception. As infertility has increased, shorter voluntary waiting periods have become normal, impacting further on the 305 day lactation figures for the most fertile animals. The results from this study are based on a relatively small population, further work on a large study group is needed.

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### 6.3.4 Other presentations

Exerts from the main work and associated research have been presented at other events;

CARS November 2012- Poster presentation "**A preliminary investigation into the effect of the using ICAR 305 day lactation figures as a parameter for selection in dairy cattle"**

2 items published in RCBS News, Cornwall

CARS June 2013- Poster presentation **"A preliminary investigation into the potential negative impact on fertility of the use of ICAR qualifying lactation figures for breed selection in high yielding Holstein dairy cattle"**

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